National Aeronautics and Space Administration

Engineering Test Facilities Guide

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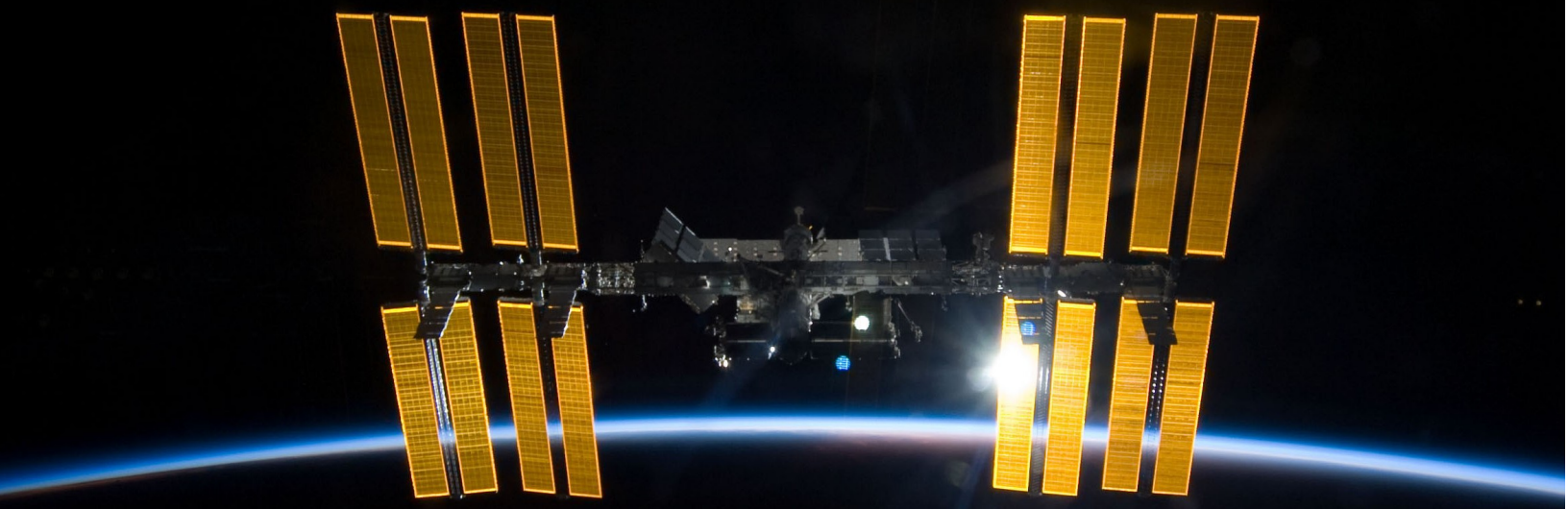
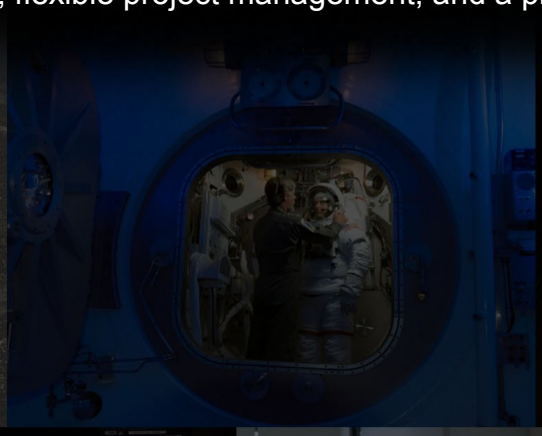
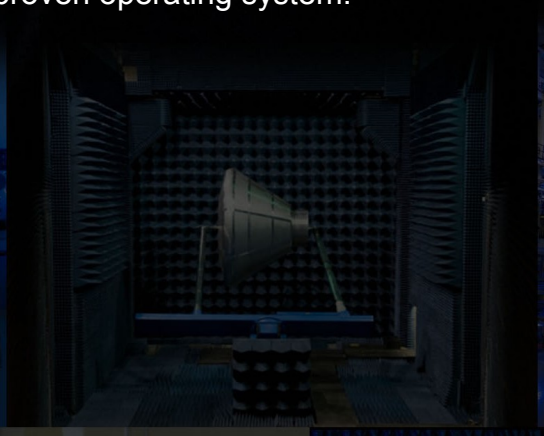
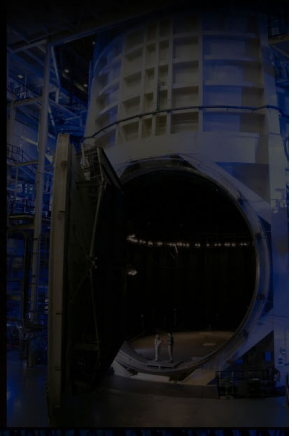
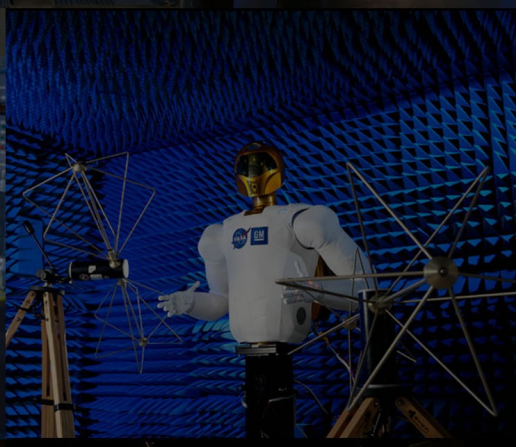


Welcome to the Johnson Space Center

Johnson Space Center's engineering teams have successfully accomplished many of the nation's most complex human spaceflight-related projects. The Center has created and refined innovative spaceflight research and development techniques that encompass all phases of human spaceflight—from highly developed design through fabrication and operations processes. Through this ongoing refinement, Johnson Space Center continues to expand its world-class capabilities, which include an expert work force, natural infrastructure, unique facilities, flexible project management, and a proven operating system.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Overview

The Johnson Space Center (JSC) is uniquely positioned to provide engineering design, development, and testing for spaceflight vehicles and systems. Capability is available in the areas of human space vehicle systems, life support systems and environmental control, flight design, integrated environment testing, and robotics. This guide describes the test and evaluation capabilities that are currently maintained in active status. This guide is divided into six technical categories. These categories are represented by the color scheme presented below.

Human Space Vehicle Systems

- Spacecraft Communications
- Structures and Materials
- Integrated Power
- Models, Simulation, and Software
- Thermal Management
- Mechanical Separation Systems
- Crew Survival
- Flight Crew Equipment

Environmental Control and Life and Support Systems

- Water Recovery Systems
- Air Revitalization Systems

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- Rendezvous, Proximity, and Docking
- Flight Mechanics
- Entry, Descent, and Landing
- Aerodynamics

Robotics

- Technology Development
- Highly Dexterous Manipulators

Doing Business With Us

We have developed customer-friendly agreements to streamline business relationships and are eager to share our unique facilities and expertise with new customers. We invite your inquiries regarding application or adaptation of our capabilities to satisfy your special requirements. Briefings on general or specific subjects of mutual interest can be arranged at JSC or at your business site.

There are two paths established for obtaining our services, depending on your organization type. The steps below summarize the typical process for planning and conducting test activities within the Engineering Directorate at JSC.

Commercial Partners

1. Commercial Partner contacts one of the JSC representatives listed below to inquire about our services.
2. JSC will provide an initial cost and schedule estimate.
3. If the estimated cost and schedule are acceptable, a Space Act Agreement will be drafted.
   Note: *Commercial Partners may be able to use an existing umbrella agreement.*
4. Once the agreement is signed, funding must be submitted to the NASA JSC Finance Office in order to proceed with work.

Government Partners

1. Government Partner contacts one of the JSC representatives listed below to inquire about our services.
2. JSC will provide an initial cost and schedule estimate.
3. If the estimated cost and schedule are acceptable, an interagency agreement or reimbursable agreement will be drafted.
4. Once the agreement is signed, a valid purchase request, such as a Military Interdepartmental Purchase Agreement, must be submitted by an authorized certifying officer.

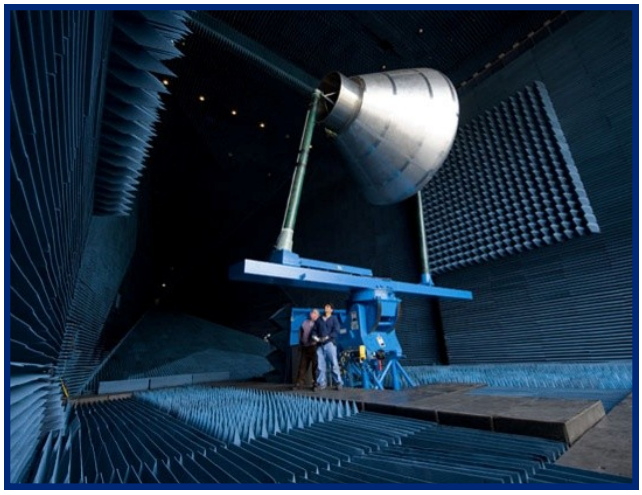
Contact Information

Associate Director, JSC Engineering
Phone: 281-483-8991
Email: jsc-ea-partnerships@mail.nasa.gov

For assistance or additional information about JSC, please visit: http://jsceng.nasa.gov

Human Space Vehicle Systems

JSC provides combined expertise in structural design, analysis, testing, dynamic loads analysis, and materials evaluations for space-faring vehicles. Specialty areas include reliable pyrotechnics, power systems and power quality, fluids management, battery performance, imagery analysis, micrometeoroid debris analysis and design, cockpit design, radiation-hardened avionics, thermal control systems, crew survivability, and reliable software.



Spacecraft Communications

Integrated Power

Structures and Materials

Modeling and Simulation

Spacecraft Communications

Space vehicle communications systems are unlike other spacecraft systems, because they interface not only with other equipment on the space vehicle but also with external equipment that is remotely located. JSC has expertise and unique facilities in which multi-element spacecraft communications systems are interfaced with relay satellites and ground elements for end-to-end testing in a controlled Radio Frequency (RF) environment. JSC also provides for the design, development, and testing of spacecraft communication systems, including evaluation of the electromagnetic radiation properties of antennas and other radiating objects.

Antenna/RF Design and Testing

JSC provides expertise in the design, development, and manufacture of antennas and RF equipment. JSC can conduct antenna and scattering tests and measurements and provide computational electromagnetic analysis.

Wireless and Radio Frequency Identification (WRFID) Laboratory

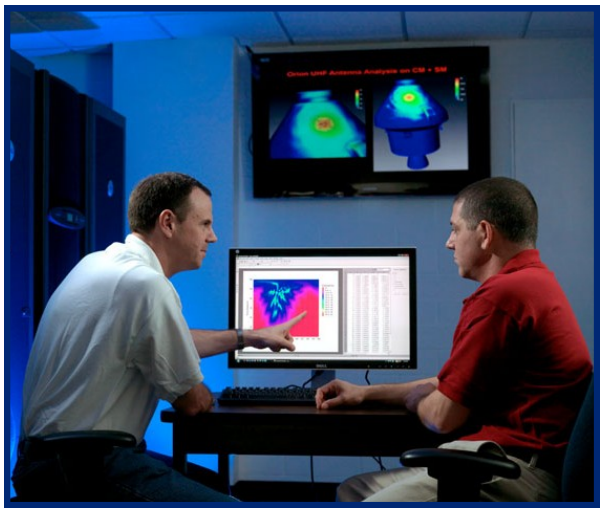
The WRFID Laboratory can facilitate the design, development, testing, and analysis of Radio Frequency Identification (RFID) and other wireless technologies for space applications. The laboratory provides for the development of antennas and RF circuits and the testing of antenna, RF circuits, and RF cables using various RF test equipment.

Computational Electromagnetics (CEM) Laboratory

The CEM Laboratory is used for full-wave, frequency domain electromagnetic simulations. The laboratory houses a computer cluster that currently contains 476 processors and 1.95 terabyte of random access memory. The CEM uses software called GEMINI (Generalized ElectroMagnetic INteractIons), which was developed at JSC.

Services Provided

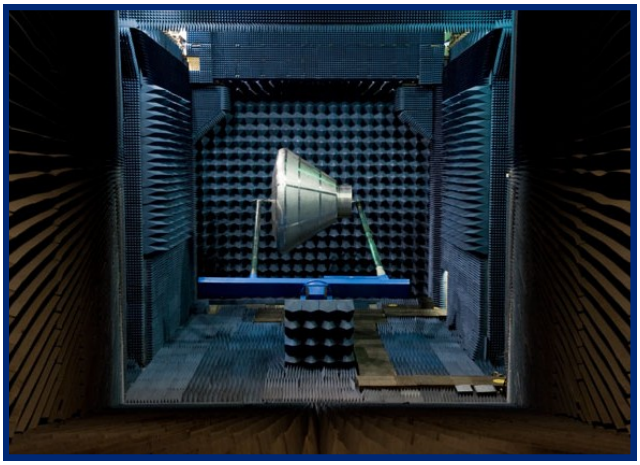
- Antenna performance characterization
- Measurement of near-and-far-field antenna radiation distribution patterns
- Radar cross-section calculations
- Design and development of microwave devices and antennas
- General three-dimensional (3-D) frequency domain electromagnetic analysis
- Antenna coupling analysis
- Verification of microwave and antenna measurements



Computational Electromagnetics Laboratory

Antenna Test Facility (ATF)

The ATF is used to test antenna radiation distribution pattern performance for spaceflight applications in electromagnetic environments conditioned to simulate free space. The frequency range of this activity spans from 200 MHz to 40 GHz. The antenna ranges are used to acquire radiation performance data by taking radiation pattern measurements. The ATF has one anechoic chamber and an outdoor antenna range. The anechoic chamber houses two antenna test facilities: the Far-Field Test Facility and the Near-Field Test Facility.



Antenna Test Facility

Antenna Test Facility Specifications

Facility	Parameter	Value
Far-Field Test Facility	Function/frequency range	Measures far-field antenna radiation distribution patterns and principal plane cuts; 200 MHz to 40 GHz frequency
	Dimensions	Flared horn shape (tapered), 150 ft long with cross section approximately 40 ft by 40 ft
	Range length	Approximately 115 ft from tip of apex to Antenna Under Test (AUT)
	Antenna mounting	Single positioner or dual positioner
	Load capability	Single positioner can handle 600 lb; dual positioner can handle 1,200 lb
	Maximum mockup size	28 ft in length on dual positioner
Near-Field Test Facility	Function/frequency range	Measures near-field antenna patterns using a raster can; 350 MHz to 4 GHz frequency range
	Antenna mounting	Hydraulic cylinder – AUT fixed in vertical position during test; dual tower positioner – AUT not fixed
	Scanning plane	38 ft by 38 ft
	Maximum antenna size	28 ft in length on dual tower; 30 ft in diameter on hydraulic cylinder
Outdoor Antenna Range	Function/frequency range	Measures far-field radiation principal plane cuts; 200 MHz to 26.5 GHz frequency range
	Range length	~180 ft from transmit antenna device under test

Human Space Vehicle Systems

Communication and Tracking Systems

JSC provides system-level performance analysis and testing, internal/external interface compatibility, end-to-end system integration, and integrity of communications and tracking, network, command and data handling, and instrumentation systems.

Services Provided

- System analysis and integration
  - Dynamic and static link budget and RF coverage analysis
  - Multipath/differentiation/reflection analysis
  - Radiation keepout zone/mask analyses
  - Signal propagation effects
  - Systems/performance trade studies
  - IP communications stack
  - Traffic model/timing/delays
- RF spectrum engineering
- Communication systems simulation and modeling
- Communication systems testbeds (e.g., PROPSim, IP testbed, STK, DECAT, FEKO, XGtd, Wireless InSite, MATLAB/Simulink, QualNet, OPNET)

HD Motion Imaging Laboratory

Communication Systems Simulation Laboratory (CSSL)

The CSSL consists of state-of-the-art computer-aided design and analysis tools used to model and simulate the performance of both proposed and actual spacecraft communication systems, subsystems, components, and parts. CSSL services include RF coverage and compatibility, end-to-end communication system performance, system design and verification, signal analysis, network simulation, and anomaly resolution. The CSSL also supports JSC spectrum management activities.

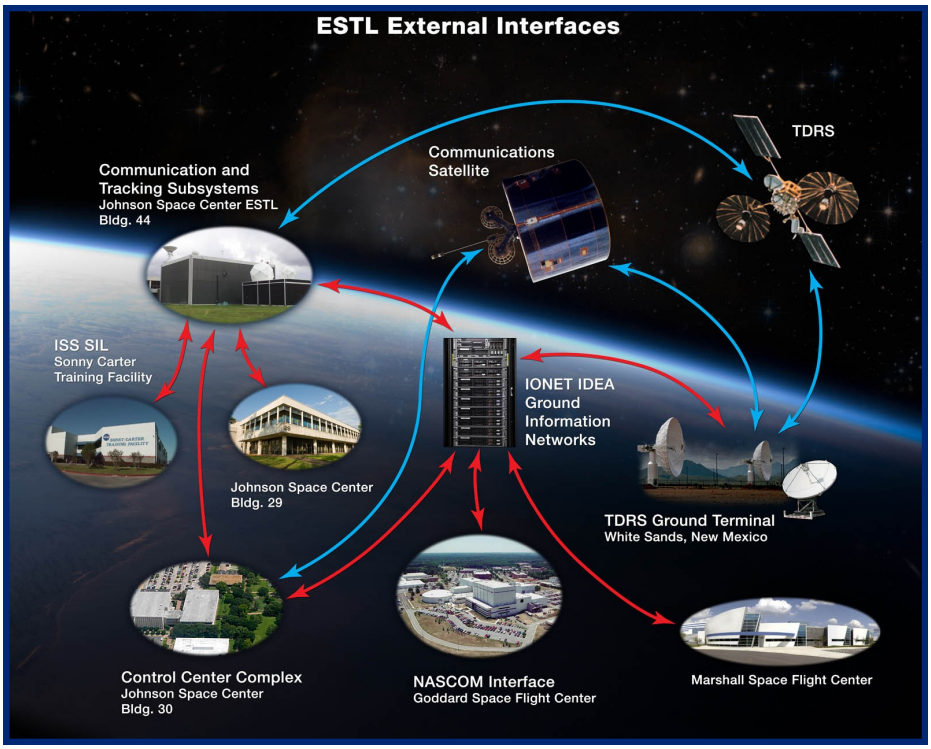
High-Definition (HD) Motion Imaging Laboratory

The HD Motion Imaging Laboratory provides high-fidelity HD evaluation, analysis, and verification testing of spacecraft video, ground facilities processing equipment, and imaging systems. HD video signals from encoders, cameras, recorders, and other devices can be tested for comparison or compliance with video standards, including quality, latency, and network performance specifications. The laboratory is configured with complete flexibility and efficiency, yet provides perfect signal integrity with no loss or degradation throughout its data signal pathways.

Global Positioning System Laboratory (GPSL)

The GPSL is a design, development, testing, and evaluation facility that allows testing of Global Positioning System (GPS) equipment with live GPS satellite signals via rooftop antennas and antenna positioners.

Electronic Systems Test Laboratory (ESTL)



The ESTL is a facility where multi-element crewed spacecraft communications systems are interfaced with relay satellites and ground elements for end-to-end testing in a controlled RF environment. This facility is used for design evaluation, RF interface compatibility verification, and system performance verification testing of spacecraft RF communications systems and their interfaces with external elements (e.g., ground stations, relay satellites, detached payloads). Space vehicle communications systems are unlike other spacecraft systems, because they interface not only with other equipment on the space vehicle but also with external equipment that is remotely located. The interface with the external equipment serves as the lone link between the Earth-based elements and the space vehicles. Thus, communications verification testing of the links between the external elements and the equipment on a crewed or unmanned space vehicle or high-valued payload is essential for successful flights.

Services Provided

- Communication verification testing between relay satellites, ground terminals, and the spacecraft
  - Installation and testing of all International Space Station (ISS) RF S-band and Ku-band communication equipment
  - Three antenna radomes for RF transmission/reception from an on-orbit spacecraft or a Tracking and Data Relay Satellite (TDRS)
- RF characterization testing for payloads, satellites, and other unmanned vehicles
- RF anomaly resolution testbed—prelaunch, real-time, and postflight
- Support of Tracking and Data Relay Satellite System (TDRSS) Network verification and validation tests, TDRS checkout, and TDRSS Network firmware checkouts
- Analysis model verification
- Ultra-high frequency, S-Band, Ku-Band, and Ka-Band RF spectrum

Spacecraft Audio Systems

Services Provided

- Uniform simulated acoustic environments for performance testing electroacoustic devices
- Ultra-low ambient acoustic noise environment for testing microphone performance and characterizing acoustic emission sources
- Low acoustic noise environment used for audio recording and subjective audio performance testing

Audio Development Laboratory (ADL)

The ADL provides for the design, development, test, and evaluation of audio sound equipment. The laboratory houses a reverberation chamber, a quiet room, and an anechoic chamber. The reverberation chamber provides uniform simulated acoustic environments for performance testing of electroacoustic devices, such as earphones with passive noise attenuation and noise-canceling microphones. The anechoic chamber provides an ultra-low ambient acoustic noise environment for testing microphone performance and characterizing acoustic emission sources. The quiet room provides a low acoustic noise environment used for audio recording and subjective audio performance testing.

Robonaut 2 Testing in ADL

ADL Specifications

Facility	Facility Size	Sound Pressure Level (SPL)
ADL	15 ft x 8 ft	125 dB SPL 30 to 500 Hz 115 dB SPL 500 to 8 kHz

Structures and Materials

JSC provides state-of-the-art laboratories to develop and evaluate, under appropriate space environmental conditions, structural, mechanical, and thermal concepts and methods of analysis and testing for space vehicle applications. Capabilities include design, development, and testing of structures, mechanisms, thermal protection systems, passive thermal control systems, and mechanical systems for the advancement of technology and space vehicle capabilities.

Structures Test Laboratory (STL)

The STL is used for static load testing of assemblies and components. Tests range from mechanical properties testing of materials to full-scale verification testing of payloads and spacecraft structures. JSC is equipped with a variety of hydraulic and electromechanical load frames with maximum load capacities ranging from 10 to 220 kip.

Services Provided

- Static and fatigue load testing using single or multiple actuators up to 220,000 lb
- 12 load frames
  - Tension and compression testing
  - Load or displacement control
- Cyclic testing up to 100 Hz
- Fracture mechanics property testing – automated da/dN testing
- Tensile, lap shear, and compression testing of materials at low and elevated temperatures
- Fatigue/fracture coupon tests
- Servo-controlled load application

STL Specifications

Parameter	Value
Load capacity	Up to 220,000 lb_f
Actuator capacity	Up to 150,000 lb_f
Stroke range	6 in. to 57 in.
Temperature range	–300 to 800 °F

Structures Test – Orion Crew Module

Structural Dynamics Testing

JSC can perform a wide range of tests needed to evaluate all aspects of structural dynamics, including vibration, vibroacoustics, modal characteristics, sound transmission loss, and shock testing. These facilities can be used to perform test and evaluation of both aerospace and nonaerospace hardware. For more information about our structural dynamics testing capabilities, see Launch Environment (page 36).

Materials Analysis

Our materials laboratories provide analytical capabilities used in the analysis and evolution of spaceflight hardware. Test and evaluation capabilities include metallography, material properties testing, microscopy, environmental testing, Nondestructive Evaluation (NDE), and analytical chemistry.

Analytical Chemistry Laboratory

Nondestructive Evaluation

- Radiographic Testing (RT)
  - Computed Tomography (CT)
  - Digital RT
  - Standard film RT
- Ultrasonic Testing (UT)
  - Phased Array UT
  - C-scan UT
  - Conventional UT
- Infrared (IR) thermography inspection
  - Flash Infrared (FIR) thermography testing
- Remote evaluation techniques
  - ARAMIS 3-D image correlation photogrammetry
  - Laser shearography
  - High speed imagery
- Eddy Current Testing (ET)
  - Array ET
  - Conventional ET
- Liquid Penetrant (PT) and Magnetic Particle (MT) inspection

Scanning Electron Microscopy

- Secondary/backscatter imaging
- Energy dispersive spectroscopy
- Scanning transmission electron microscopy
- Electron backscatter diffraction
- Carbon and precious metal thermal/ sputter coaters

Analytical Chemistry

- Chemical analysis
  - Fourier transform infrared spectrometry
  - Pyrolysis gas chromatography/mass spectrometry
  - Ultraviolet-Visible-Near Infrared
  - Raman spectrometry
  - Near infrared photoluminescence
- Thermal analysis
  - Differential scanning calorimetry
  - Thermogravimetric analysis
  - Laser flash technique (thermal diffusivity)
- Other analysis
  - BET surface area porosity analysis
  - Optical instruments
  - Wet chemistry techniques

Metallography

- Abrasive cutoff and precision diamond cutting
- Mounting, polishing, and etching
- Hardness testing
- Inverted, stereo, and upright microscopy
- Reflective bright field, dark field, Differential Interference Contrast (DIC), Circular DIC, polarized, and transmitted microscopy
- Imagery and dimensional analysis

Textiles and Fiber/Fabric Insulations

Our textile and fiber/fabric insulation laboratories provide for the development of textile applications and evaluation of items worn by the crew for suitability. We also develop textile and insulation materials for space environments that may provide radiation and dust protection, pressure retention, and puncture or wear resistance. Our analysis laboratory provides for evaluation of thermal properties, strength, fiber bond, wear, hardness, and stress of textiles and fiber/fabric insulations.

Textiles and Fiber/Fabric Insulation Laboratory

JSC offers expertise in textile development from design prototyping to manufacturing. JSC has designed, developed, and manufactured flight textile items, such as thermal blankets for shuttle payloads, thermal blankets for Extravehicular Mobility Unit (EMU) helmet cameras, Extravehicular Activity (EVA) and Intravehicular Activity (IVA) bags, and debris shields and straps for EVA equipment.

Advanced Materials Laboratory

Our textile testing capability meets industry and government standards. Our capabilities are unique in that they measure thermal properties (thermal conductivity and coefficient of thermal expansion) of textile goods in thermal-vacuum environments that range from cryogenic to elevated temperatures. The Titan Instrument Guarded Hot Plate is the only unit world-wide that completely meets the latest standards (ISO 8302, ASTM C 177, DIN/EN12667).

Titan Instrument Guarded Hot Plate

Internal Volume	Pressure Range	Temperature Range
300 mm	1 x 10^{-5} to 760 torr	–160 to 190 °C

Thermal Protection Systems

The 13 Megawatt Arc Tunnel provides the capability to perform aerothermal heating environment tests necessary for the screening, development, and certification of spacecraft Thermal Protection Systems (TPSs). For more information about our TPS test capabilities, see Reentry Environment (page 49).

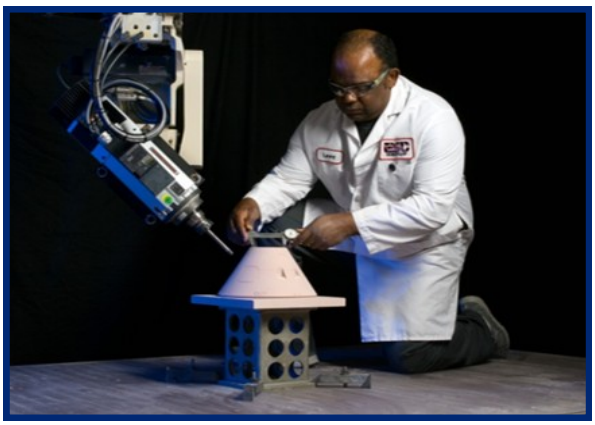
Fabrication

JSC fabrication facilities provide the resources, materials, and labor necessary to produce quality flight, ground support, and prototype hardware. JSC offers experience and expertise in precision machining, sheet metal fabrication, welding, cleaning, hydrostatic testing, coatings application, soft goods fabrication, metal finishing, models and plastics fabrication, and electronics fabrication and assembly.

Services Provided

- Flight and unique hardware fabrication
  - Specialize in new and one-of-a-kind hardware
  - Fabricate direct from model or print
- Composite manufacturing – Advanced composite materials, such as graphite or boron, in the construction of advanced space structures
- Precision machining and Research and Development
  - Manual and computer numerically controlled lathes and mills
  - Capacities from micro to large 3- and 5-axis milling
- Welding – Gas tungsten, gas metal, and shielded metal arc welding; silver brazing; and friction stir welding
- Precision sheet metal fabrication
- Soft goods fabrication
  - Expandable structures
  - Soft goods for EVA hardware and tools
  - Micrometeoroid Orbital Debris ballistic debris shields
- Metal finishing and surface preparation
  - 26 30 in. x 24 in. x 60 in. process tanks
  - Type 2 anodizing up to 30 in. x 15 in. x 60 in.
- Models and plastics
- Precision cleaning (Class 50 to 1000)
- Electronic hardware manufacturing – Fabrication and assembly of electronic flight and nonflight hardware
- Printed wiring boards and assemblies
  - Cleanliness to less than 0.010 °S/cm for a 75% alcohol/water solution
  - Vacuum deposition parylene conformal coating (vacuum range from 1 bar to 0.28 mbar)
- Prototype microwave circuit board fabrication

Precision Machining



Dimensional Inspection

Integrated Power

JSC provides test facilities and personnel that encompass many of the fluid and energy conversion systems required for human exploration and development of space, including power generation and storage, fluid storage and distribution, and electromechanical and hydraulic actuation. Test capabilities include battery performance, abuse and life-cycle testing, power distribution system testing, fuel cell testing, high voltage and corona detection, connector and wire testing, and power quality.

Battery Systems Test Facility

The facility provides abuse, performance, and space environment tests of batteries and cells for applications ranging from comfort devices for astronauts, such as satellite phones, portable digital assistants, and laptops, to life-saving equipment used in the space suit and backup power supplies. Many of these batteries are high energy and contain toxic materials. With such a wide diversity of batteries, it is important to understand the specific dangers that each battery type and chemistry presents.

Services Provided

- Battery performance testing
  - Cell chemistry evaluation
  - Endurance cycling
  - Long-term storage
  - Operate to failure
  - Thermal and vacuum environment cycling
  - Vibration testing
- Variety of cell chemistries – Lithium ion (Li-ion), nickel metal hydride, alkaline, and lead acid
- Battery abuse testing
  - High-temperature exposure and heat-to-vent testing
  - Overcharge and overdischarge characterization
  - Positive temperature coefficient failure testing
  - Short-circuit testing
  - Crush and drop testing
  - Destructive physical analysis

Battery Performance

Voltage Range	Temperature Range
Ranges vary by test stand 0 to 600V	–200 to 350 °F

Capabilities
• 12 systems ranging from low current/voltage to high current/voltage • Constant voltage, current, and power modes provided • Long- and short-term cycling • Determine optimal charge and discharge rates • Thermal capacities/vacuum tolerance

Battery Abuse

Facility	Volume	Pressure Range
2-Ft Chamber	2 ft Dia x 36 in. L	0.001 torr to 100 psia
4-In. Chamber	4 in. Dia x 30 in. L	0.001 torr to 100 psia

Temperature Range	Overcharge/Discharge Short Circuit
–300 to 500 °F	12 Channel 30V 15A

Electrical Power Systems Testbed

The Electrical Power Systems Testbed is a modular power laboratory that provides a high-fidelity testbed for end-to-end power system testing to verify power system design. The laboratory provides for the research, development, and testing of power breadboards and houses universal single- and multiple-channel power testers to perform power quality testing. The laboratory also provides for in-the-loop high-voltage battery testing.

Services Provided

- Integrated power system verification testing – High-fidelity power emulators and load emulators
- Support for Li-ion battery-in-the-loop testing
- Off-nominal power testing
  - Envelope limit testing of hardware in a system-level test environment
  - Fault injection scenarios in true off-nominal conditions
- Automated power quality testing including, but not limited to
  - Rapid regression testing
  - Rapid test development using "canned" tests

Exploration Electrical Systems Testbed

Fuel Cell Testing

A fuel cell is an electrochemical power-generation device that takes hydrogen and oxygen reactants and converts them into electrical power, heat, and potable water, which can be used for life support and cooling. Testing and characterization of fuel cells are ongoing at JSC to support NASA's exploration initiative. We have experience in testing a variety of fuel cell technologies that use different electrolyte materials and operate over a wide range of temperatures. JSC's Fluid Systems Test Facility has two fuel cell test stands that provide the following capabilities:

- Unattended fuel cell testing
- Programmable Direct Current (DC) load banks to dissipate fuel cell power up to 150 kW at up to 100V
- Oxygen flow rates to 8 scfm and hydrogen flow rates to 16 scfm
- Portable reactant supply system
- 250 data channels designed for fuel cell tests

Models, Simulation, and Software

JSC offers capabilities in developing high-fidelity, real-time, human-in-the-loop engineering simulations with math models, scene generation, and realistic control station mockups. Expertise is available in software development, including real-time, mission-critical, embedded software for flight and ground systems; software integration; and hardware-in-the-loop testing. We provide computer graphics and model development for engineering visualization as well as state-of-the-art facilities for testing advanced simulation environments, allowing integration of multiple models into a single simulation.

Model Development

JSC develops high-fidelity, real-time graphical simulations that are used to support both engineering analysis and flight crew training needs. We also provide graphics models and real-time simulation models throughout NASA and for cooperative activities with other government agencies and ISS partners.

Engineering DOUG Graphics for Exploration (EDGE)

Edge is a 3-D rendering package used in all of the on-orbit simulations (engineering and training) at JSC and is available for public release through the JSC Technology Transfer Office.

Integrated Graphics Operations and Analysis Laboratory (IGOAL)

The facility produces highly realistic animations of space operations. Modeling and animation are performed in AGEA, an integrated 3-D modeling, animation, and visualization tool. The facility that researches algorithms for computer graphics image generation develops graphics software tools for the assessment of real-time and non-real-time operations, generates video documentation of simulation results and conceptual scenarios, and performs human-in-the-loop systems engineering and analysis.

Services Provided

- 3-D engineering visualization
  - Data visualization
  - Advanced concept visualization
  - Proof-of-concept visualization
  - Accident reconstruction
- 3-D modeling
  - Model reduction and correlation
  - Texture, bump, and reflection mapping
  - Format conversion
- 3-D graphics custom software development
  - Development of custom algorithms for 3-D computer graphics
  - 2-D displays and controls
  - Physics and lighting simulations

IGOAL 3-D Graphics Model

Simulation

We have multiple facilities that provide high-fidelity, real-time graphical simulations used to support both engineering analysis and flight-crew training needs. Our laboratories can develop graphics models and real-time simulation models or incorporate models from many different providers.

Simulation	Services Provided
Human-in-the-loop simulation	• Integrated engineering simulation with high-fidelity dynamics and pilot environment models designed for tasks that require crew in the loop • Simulation of multiple free-flying vehicles with accurate six-degree-of-freedom equations of motion
Guidance, Navigation, and Control (GN&C)	• High-fidelity, six-degree-of-freedom simulation builds of single- and multiple-vehicle missions for various flight phases • Development of high-fidelity models and simulations used for integrated GN&C design and analysis • High-fidelity visualization of real-time GN&C operations
Mechanical interfaces	• Open- and closed-loop testing of automated rendezvous and docking systems • Closed-loop testing of mating interfaces, including contact forces • Physical emulation of spacecraft motion with motion platforms
Communication systems	• The performance of proposed and actual spacecraft communication systems, subsystems, components, and parts is modeled and simulated. • Services include RF coverage, communication systems performance, signal analysis, frequency management, RF compatibility, and anomaly resolution

Reconfigurable Operational Cockpit (ROC)

The ROC is a reconfigurable cockpit mockup located within a 24-foot-diameter hemispherical dome upon which one continuous image is projected. The ROC allows crewmembers and engineers to perform tests, evaluations, or training in a controlled cockpit environment while viewing a modeled external environment through the cockpit windows.

Reconfigurable Operational Cockpit

Advanced GN&C Development Laboratory (AGDL)

The AGDL provides the computational resources required to build high-fidelity, six-degree-of-freedom simulations of single- and multiple-vehicle missions for various flight phases. The laboratory provides excellent visualization capabilities and real-time (human-in-the-loop) simulation capabilities. For more information about our GN&C simulation capabilities, see Guidance, Navigation, and Control (page 53).

Human Space Vehicle Systems

Systems Engineering Simulator (SES)

The SES is a real-time, crew-in-the-loop engineering simulator for the space station and advanced programs. It provides the ability to test changes to existing space vehicles and flight software, test the interaction of a new vehicle system with existing systems, create models of new vehicles (that may or may not exist yet) for engineering analysis, and evaluate display and control concepts and modifications. All of these functions are performed in a controlled yet flexible development environment. Models and capabilities developed for one customer can be used by other customers.

SES Beta Dome

Services Provided

- Simulation of multiple free-flying vehicles with accurate six-degree-of-freedom equations of motion
  - Docking contact dynamics
  - Aerodynamics
  - Thruster plume impingement
  - Vehicle control systems
  - Robotic manipulator dynamics
- Engineering studies
  - Proof of concept: test of experimental operations to validate their values
  - Operational feasibility: flight-like environment within the environment of the simulator
  - Design assessment: analysis of vehicle interactions
- Mission support and evaluation
  - Procedure development: flight procedure development through simulation of missions
  - Training: training of flight crew, controllers, and other personnel in rendezvous/ proximity operations
  - Flight support: 24-hour support during missions to respond to on-orbit contingencies

Reduced Gravity Simulation

JSC provides the capability to simulate reduced gravity environments, such as lunar, Martian, or microgravity. Reduced gravity simulation can be used for testing, development, and training for human and hardware applications. For more information about our partial gravity simulation capabilities, see Reduced Gravity Environment (page 47).

Six-Degree-of-Freedom Dynamic Test System (SDTS)

The SDTS is a real-time, six degree-of-freedom, short-range simulator with a motion base. It has the capability to test full-scale docking and berthing systems. For more information about our Rendezvous and Docking Simulation capabilities, see Proximity, Rendezvous, and Docking (page 55).

Kedalion Laboratory

The Kedalion laboratory supports software development, integration, testing, and analysis with an emphasis on flight software. It contains flight-like computer processors; high-fidelity, six-degree-of-freedom closed-loop simulations; human-in-the-loop hand controllers and display units; high-definition graphics simulation displays; full software development tool suites; and several GN&C sensor hardware simulators. The hardware simulators include a rate table (used to impart angular rates to a mounted inertial measurement unit) and a GPS signal generator (used to simulate flight by generating GPS RF signals that are fed into GPS receiver hardware). The laboratory uses time-triggered gigabit Ethernet and Mil-Std 1553, among other bus topologies for flight bus emulations.

Kedalion Laboratory

Robotic Motion Platform (RMP) and Dexterous Manipulator Testbed (DMT)

The RMP and DMT are large, model-following, motion-base simulators that are hydraulically actuated, computer controlled, and designed to maneuver payloads for close-in worksite operations concentrating on hardware contact. For more information about our robotics capabilities, see Robotics (page 59).

Virtual Reality Laboratory (VRL)

The VRL is an immersive environment facility that provides real-time, integrated EVA/Robotics procedure development/training, Simplified Aid for EVA Rescue (SAFER) flight training, and integrated zero-g mass handling simulations for large objects (> 400 lb) handled by EVA crew members. The VRL is the developer of the EDGE graphics package.

Hardware-in-the-Loop Autonomous Landing and Hazard Avoidance Technology (ALHAT) System Testbed (HAST)

The laboratory integrates software models of vehicle dynamics/systems with hardware models (e.g., sensors) to provide real-time simulation of closed-loop lander systems supporting ALHAT. The laboratory is an integrated real-time testing facility utilizing software, hardware, and emulators from various developers to do the following:

- Execute Hazard Detection System and Terrain Relative Navigation software on a protoflight-like processor
- Execute Autonomous Flight Manager and GN&C software on a protoflight-like processor
- Incorporate relative navigation sensor hardware or emulators in closed-loop testing with a lunar simulation
- Provide an interface for crew reach-in/crew-in-the-loop functionality

Communication Systems Simulation Laboratory

The CSSL is used to model and simulate the performance of proposed and actual spacecraft communication systems, subsystems, components, and parts. For more information about communication systems simulation, see Spacecraft Communications (page 9).

Computational Electromagnetics Laboratory

The CEM Laboratory is used for full-wave, frequency domain electromagnetic simulations. For more information about antennas and communication systems simulation, see Spacecraft Communications (page 7).

Software

JSC provides leadership and technical expertise in spaceflight software development and Vehicle Systems Management (VSM). Systems engineering is performed to assess flight vehicle operations, the appropriate application of automation and autonomy, and the performance of flight processor architectures. VSM includes Fault Detection, Isolation, and Recovery (FDIR); vehicle reinitialization; mode management; resource management; onboard checkout; and health and status data management.

Services Provided

- Software development
  - Flight and ground systems
  - Real-time, mission-critical, embedded software
  - Software integration and hardware-in-the-loop testing
  - Capability Maturity Model Integration certified software development organization
- Vehicle systems management
  - FDIR software
  - Automation for human workload reduction
  - Flight safety enhancement
  - Resource management
- Automation and robotics
  - Hardware and software integration for human robotic systems
  - Teleoperation and autonomous system control
  - Automation for operations
- Software testing and simulation
  - Advanced simulation environments that allow integration of software developed for many different platforms
  - Integration of multiple models into a single simulation

Thermal Management

JSC provides expertise and facilities for the development and testing of flight and new technologies for spacecraft and extravehicular equipment thermal control systems. JSC has provided design, development, test, and analysis for the ISS Active Thermal Control System (ATCS), EVA systems, ISS freezers, and advanced ATCS technologies.

Services Provided

- Development and testing of ATCS and related technology
- Testing and analysis of ATCS
  - Payload heat exchanger simulation
  - Hydraulic heat exchanger simulation
  - ATCS radiation simulation
  - Component level life testing
  - Thermal properties analysis
  - Low-temperature performance evaluation
  - Environmental Control and Life Support Systems compatibility
  - Materials compatibility
- Testing and analysis of systems leveraging experience with the following systems:
  - ISS ATCS
  - EVA systems
  - ISS freezers
  - Crew Return Vehicle ATCS

ATCS Laboratory

The ATCS Laboratory provides the ability to test active thermal control systems in a laboratory environment using chiller carts, cold plates, heat loads, and other thermal system simulators to determine thermal system performance. Capabilities include thermal control system fluid evaluation, systems test and analysis for heat acquisition and heat transfer, evaporator and condenser evaluation, and development and performance evaluation of radiators.

Cold Stowage Systems Laboratory

The Cold Stowage Systems Laboratory provides hardware testing and processing capabilities for cold stowage hardware. Products developed and tested in the laboratory include the ISS Cold Enclosure Phase Change Material (PCM) Augmenting Capsule (ICEPAC), the General Laboratory Active Cryogenic ISS Equipment Refrigerator (GLACIER), coldbag, and the Minus Eighty degree Laboratory Freezer for ISS (MELFI) engineering unit.

Cold Stowage Systems Laboratory

Integrated Environment Testing of Thermal Control Systems

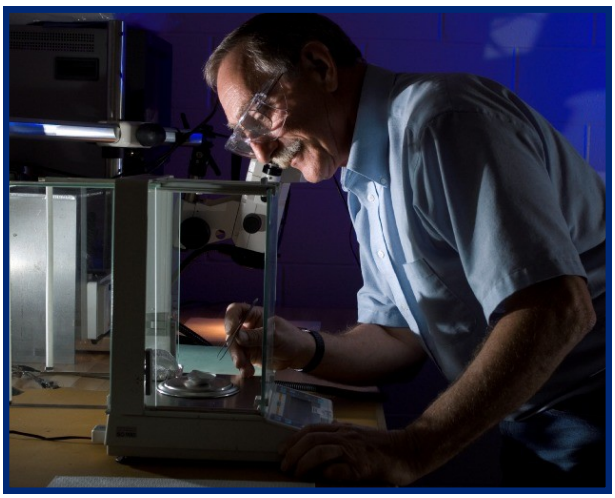
JSC has expertise and facilities for the simulation and testing of passive thermal control systems and technology. For more information about our passive thermal control system capabilities, see Reentry Environment (page 49).

Mechanical Separation Systems

JSC has a long heritage of providing safe, reliable pyrotechnic solutions for aerospace applications. The Pyrotechnics Test Facility provides for testing pyrotechnically actuated devices and is capable of subjecting hardware to vibration environments encountered during launch and landing. The facility has an explosives loading and handling room and pyrotechnics storage in earth-covered bunkers. The facility provides the unique capability to perform NASA Standard Initiator (NSI) testing at –420 °F and is responsible for lot testing and providing NSIs for all NASA spacecraft applications.

Services Provided

- X-ray, dimensional inspection, and proof pressure and functional testing of pyrotechnic devices and full systems
- Loading of propellants, pressure cartridges, and explosives
- Vibration of hazardous test articles, including pressurized systems and explosive materials
- Nonlinear finite element analysis utilizing LS-DYNA and DYTRAN
- Internal ballistic analysis
- VISAR velocity measurements up to 10,000 meters/second
- High speed digital video up to 4 million frames per second



Loading Pyrotechnic Initiator Device

Hydraulic Loading/Firing

Work Envelope	Orientation	Temperature Range	Unique Features
12 In. Dia x 3 Ft L	Horizontal	–300 to 350 °F	• Tensile loads up to 680,000 lb_f • Moment loads up to 240,000 in-lb_f

Pyrotechnic Auto Ignition Chamber

Work Envelope	Orientation	Temperature Range	Unique Features
4 In. Dia x 12 Ft L	Vertical	Ambient to 1,500 °F	Remote operation, programmable ramp rates, and hold periods

* We also can provide vibration, thermal, and thermal-vacuum testing of pyrotechnic devices. For more information about these capabilities, see Integrated Environment Testing (page 35).

Crew Survival

JSC is a leader in Launch/Entry Suit and Crew Protection Systems. Expertise is available in development, testing, analysis, certification, and failure investigation of launch/entry pressure suits, vehicle seats, occupant protection systems, survival radios, life rafts, emergency breathing systems, automatic-inflation life preservers, and various other crew-survival equipment items.

Services Provided

- Metabolic load physiological limitation studies to determine crewmember heat stress with multiple suit configurations
- Carbon Dioxide (CO_2) buildup and washout testing to disperse helmet CO_2 and prevent hypercapnia
- Occupant protection impact testing
- Suit material outgas investigation at vacuum
- Oxygen (O_2) flammability assessment for emergency breathing hardware
- Multiple crewmember life raft stability studies

Crew Escape Laboratory – ACES Suit

Crew Escape Laboratory

The Crew Escape Laboratory is used to process launch and entry suit components and assemblies under pressure and high-altitude conditions. The laboratory currently works with the Advanced Crew Escape Space Suit System (ACES). ACES provides a survivable environment for a crewmember during launch and reentry mission phases in nominal and emergency scenarios. The suit is a full-pressure suit that delivers oxygen to the crewmember for breathing, suit pressurization, and anti-g suit inflation, and it is certified up to 100,000 feet in altitude. The suit system provides liquid cooling, emergency breathing, and escape hardware to aid survivability through bailout and land/water egress events.

Flight Crew Equipment

JSC designs, builds, and tests tools and equipment to make work easier and safer in space. Expertise is available for research design, development, test, and operational support for IVA and EVA tools and equipment to support ISS and future spaceflight programs.

Services Provided

- EVA tools and equipment development for EVA operations
- EVA tools developed
  - TPS repair system and tools
  - EVA trace gas analyzer
  - Fluid line repair kit
  - Solar array recovery tools
- IVA tools development for ISS
  - IVA flight crew equipment and tool restraints
  - Mobility aids
  - Housekeeping equipment
  - Portable illumination
- Prototyping – Fabricate multiple hardware concepts to address key functional requirements
- Testing
  - Reduced or zero-gravity testing
  - Human-rated thermal-vacuum testing
  - Pressurized glove box
  - Vacuum glove box

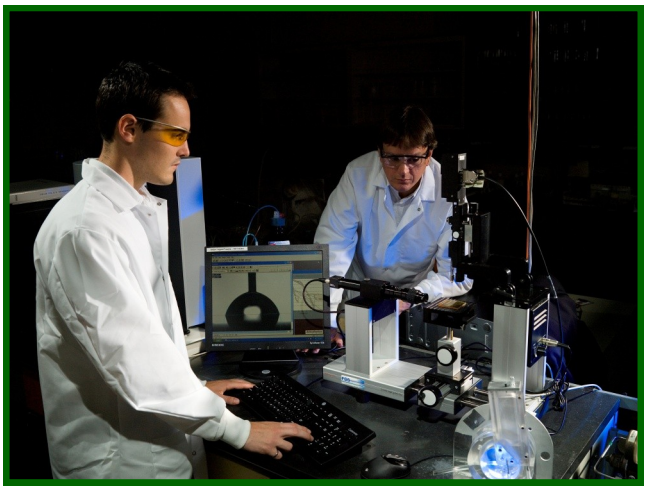
TPS Repair System

IVA Work Light and Multimeter

Environmental Control and Life Support Systems

JSC is the world leader in environmental control and life support systems for human spaceflight, including air revitalization systems, water recovery systems, waste management, and regeneration systems. JSC personnel have unique knowledge in the areas of air quality, potable water, urine monitoring, regenerative fluids, and hygiene activities.

Water Recovery Systems



Water Analysis

Gas Analysis

Air Revitalization Technology

Water Recovery Systems

JSC provides expertise in design, development, test, and maintenance of hardware to provide potable water aboard the ISS and future spacecraft. Capabilities include evaluation of water recovery technologies, chemical and physical analyses of water and wastewater systems, and technology development for future spacecraft.

Services Provided

- Test, analysis, and development of water recovery systems
  - Wastewater Collection and Transportation System
  - Biosafety level 2 microbiology laboratory
- Microbiology and wastewater testing and analysis
  - pH and conductivity
  - Total organic carbon and total inorganic carbon
  - Total nitrogen, iodine, chlorine, phosphates, ammonium, and many other ions
  - Turbidity
  - Surface tension
  - Total solids, dissolved solids, and suspended solids
  - Dissolved oxygen and chemical oxygen demand
  - Absolute color
  - Alkalinity
  - Metals

Wastewater Collection and Transportation System

The Advanced Water Recovery Systems Development Facility (AWRSDF) is home to the WWCTS, where prospective crew cleanser products (e.g., shampoo or toothpaste) are used by test donors to produce simulated spacecraft wastewater. The WWCTS accepts laundry, urine, shower, and hand wash (sink) donations. Two different wastewater loads can be collected simultaneously into independent tanks. This allows for stand-alone collection of a donation for use in small-scale testing.

Advanced Water Recovery Systems Development Facility

The AWRSDF provides a test area for all facets of spacecraft water recovery systems, including wastewater pretreatment, primary processor technologies, brine water recovery, postprocessors, water filtration, and personal hygiene. Included in the AWRSDF is a biosafety level 2 microbiology laboratory where advanced potable water disinfection technologies are tested. AWRSDF test area specifications include

- -30 °C and -80 °C refrigerators
- Light and dissection microscopes
- Flow bench and numerous test benches
- Rotary evaporator
- Freeze dryer
- LabWare washer

Water Analysis Laboratory

Water Analysis Laboratory

The Water Analysis Laboratory provides analytical capabilities to support advanced water recovery systems. Water sample analyses that we have performed include examination of physical properties, quantification of metal content, and quantification of organic and inorganic content.

Analytical Specifications

- 1 – 100 mg/L measurement of total organic carbon, total inorganic carbon, and nitrogen
- 0.5 – 10 mg/L measurement of total organic and inorganic carbon
- pH (0 – 14), conductivity (0.5 microSiemens – 12.9 milliSiemens), dissolved oxygen (0 – 20%) via dedicated probes
- 0.2 – 100,000 NTU turbidity
- 0 – 10000 mg/L chemical oxygen demand, 0.010 – 1.3 mg/L phosphate, 0 – 10 mg/L iodine (molecular and ionic), 0.010 – 4 mg/L chlorine, 0 – 25 mg/L ammonium 1 – 1,000 mN/m surface tension, and determination of critical micelle concentration via surface tension titration
- 3 – 10 mg/L I2 via iodine titration
- 0 – 10% active oxygen (percent oxygen titration of Oxone)
- 0 – 200 mg per volume sample total solids, dissolved solids, and suspended solids
- 0 – 500 color units of absolute color
- 25 – 500 meq/L calcium carbonate (CaCO3) for alkalinity
- 0.1 – 10 ppm ions
- 100 – 10,000 µg/L metals
- 0 – 10 mg/L atrazine and furfuryl alcohol
- Particle imaging

Biological Processes Development Facility

The Biological Processes Development Facility is a biosafety level 2 laboratory where advanced potable water disinfection technologies are tested. Laboratory specifications include the following:

- Two low-temperature incubators, one high-temperature (37 °C) incubator, and one shaker/incubator
- One small and one large autoclave
- Autoplater and electronic counter
- Centrifuge
- Laminar flow hood
- Biosafety bench
- Ultrapure water system

Biological Process Development Facility

Air Revitalization Systems

Our air revitalization team provides research, development, test, and maintenance of systems that create a livable cabin atmosphere for spaceflight applications. We provide expertise in evaluating air revitalization technology in the functional areas of CO_2 removal, CO_2 reduction, O_2 generation, and trace contaminant control.

Services Provided

- Air revitalization system testing
  - CO_2 removal and reduction
  - O_2 generation
  - Trace contaminant control

Air Revitalization Technology Evaluation Facility (ARTEF)

ARTEF is a test facility for evaluating air revitalization technology. The test facility can accommodate several independent test articles simultaneously as well as integrated hardware evaluations of multiple components. The facility can accommodate end-to-end operation and long-term testing of integrated air revitalization subsystems. The facility provides gaseous CO_2, nitrogen (N_2), and O_2. Multiple vent lines and a deionized water source are available. A human metabolic simulator is also available to simulate the primary humidity and CO_2 effects of one to six persons in the enclosed atmosphere.

Gas Analysis Laboratory

The Gas Analysis Laboratory provides analytical capabilities in support of air revitalization. Analyses performed include qualitative and quantitative analyses of trace components, moisture measurements, chemical identification, and contamination analysis. Additionally, we have the capability to analyze many liquids, polymers, and other solid substances. Laboratory specifications include the following:

- Facility air, CO_2, and Gaseous Nitrogen (GN_2) supplied at 100 psig and regulated to 5 psig
- Air flow rate of up to 46 standard liters per minute at pressures up to 5 psig
- CO_2 flow rate up to 49 mL/min
- Scroll pump vacuum capability to 0.04 torr with water vapor
- Bubbler for humidity control/source of up to 100%
- Trace gas capability with flow rates of up to 18 mL/min

All flow rates can be modified with change out of rotometer flow tubes.

Gas Analysis Laboratory

Space Suit Design and Development

JSC is the world leader in the design, development, testing, verification, and implementation of space suits. Space suits are unique in that they are miniature, customized spacecraft. They must provide environmental protection, mobility, and life support to the crewmember during spacewalks. JSC personnel have a vast knowledge of the technical challenges associated with space suit technology, including knowledge of mobility, sizing, life support, ventilation, hydration, and waste management. JSC experience covers the full life cycle, from basic design through development, testing and operational support.

Services Provided

- Space-suit design and development
  - Pressure garment design
  - Glove design
  - Mobility and sizing
  - Helmet/visor design
  - Life-support umbilical design
- Suit maintenance and operations
- Portable life-support technologies
  - Thermal control
  - Ventilation
  - Oxygen systems
  - Contaminant control
  - Hydration
  - Waste control
- Space-suit testing, verification, and training
  - Suit checkout
  - Altitude testing
  - Thermal-vacuum testing
  - Flight crew training

EVA Systems

Flight-Like Simulation of EVA Hardware

Extravehicular Activity Systems

Advanced Space Suit Development Laboratory

The Advanced Space Suit Development Laboratory provides the capability to fabricate and test space suit assemblies, components, and related ancillary EVA hardware system elements. Laboratory capabilities include the development, fabrication, and testing of proof-of-concept and new technology space suit assemblies, EVA components, and mobility systems. The laboratory supports a variety of ground-based (sea-level) space suit testing as well as life-cycle, mobility, and torque range testing of suit components.

Advanced EVA Life Support Laboratory

The laboratory provides testing capabilities for space suit life support components and subsystems. A bench is included to simulate the loads imposed by a human on the water and ventilation loops of the life support subsystems. The bench can test at a wide range of sub-ambient and above ambient conditions. Hydrogen and oxygen supplies and appropriate monitoring equipment are available for fuel cell tests and other hazardous system tests. A CO_2 gas cart and bubbler provides metabolic CO_2 and humidity simulation and measures CO_2, O_2, and humidity levels. In addition, complete water and ventilation loops are available to evaluate component dynamics and interactions at a full system level.

Vehicle Interface Umbilical System

Extravehicular Mobility Unit Laboratory

The EMU testing facility is maintained as a controlled work area. Located within the controlled work area is a Class 10,000 clean room. The facility is configured to service and test the majority of the Life Support Subsystem and Space Suit Assembly components and systems of the EMU. Capabilities include development and life extension testing, testing of EMU components and systems, fit checks, and anomaly and failure investigation.

EMU Laboratory

EVA Systems Testing

JSC has expertise and facilities for the development, certification, and parametric testing of life support systems for humans in the hostile environment of space. Each of the altitude chambers is configured for a particular type of testing; however, within the chamber's capabilities, each chamber complex may be used to perform other types of tests.

11-Foot Chamber

The 11-Foot Chamber is equipped with dual airlock compartments of 9 ft and 10 ft used for human testing in a vacuum environment and for space suit development. A third compartment, referred to as a "cabin" (approximately 260 ft^3 volume), is also available for reduced pressure testing. The chamber features a treadmill, crew weight relief, and the necessary support systems for reduced pressure crew operations.

11-Foot Chamber

Space Station Airlock Test Article (SSATA)

The SSATA chamber was developed to support the ISS Program for Airlock and EVA hardware testing, verification and certification, and flight crew training. It is a human-rated, high-fidelity, 1-g Airlock facility that provides flight-like simulation of Airlock and EVA operations in pressures ranging from vacuum to 1 atmosphere. Like the ISS Airlock, this facility contains two chambers—the Equipment Lock and Crew Lock—which are connected by a common bulkhead. Adjacent to the Crew Lock is a Vacuum Plenum, which is used to simulate space vacuum. The interior configuration of the Equipment Lock and Crew Lock resembles the flight Airlock while accommodating 1-g operations.

Space Station Airlock Test Article (SSATA)

Chamber B

Chamber B is used for human testing in a vacuum environment and for crewed space operations testing. Chamber B is a human-rated chamber equipped with a traversing monorail that provides weight relief to one suited crewmember at a time. The chamber also has dual crew locks to provide easy access to the test articles and a means of transporting test crewmembers to and from the test environment during tests.

Dual Glove Box

The Dual Glove Box is a human-rated thermal-vacuum chamber that allows the use of dual, elbow-length EMU arms and gloves for test operations and thermal-vacuum conditions. Features include glove ports that will accommodate EMU gloves/arm bearings (also configurable for other designs), thermal shrouds, and a work surface capable of creating a –300 °F to +300 °F environment using Liquid Nitrogen (LN_2), GN_2, electric heaters, and 1 x 10^{-5} range ultimate pressure.

8-Foot Chamber

The 8-Foot Chamber is primarily used with a machine to simulate a human metabolism in Portable Life Support Systems testing. Canned-man simulators are used primarily to provide controlled metabolic loading to life support systems under evaluation and for parametric testing.

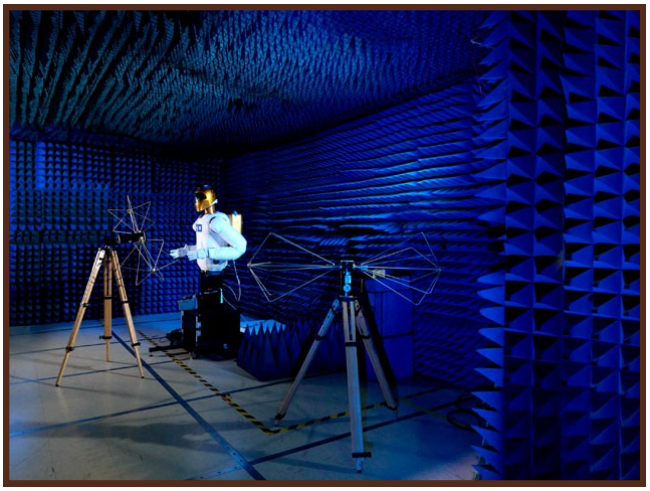
Facility	Internal Volume	Pressure Range	Temperature Range
8-Foot Chamber	8 Ft Dia x 14 Ft L	1 x 10^{-2} to 760 torr	N/A
11-Foot Chamber	11 Ft Dia x 19 Ft L	1 x 10^{-2} to 760 torr	N/A
SSATA	Equipment Lock: 1,100 ft^3 Crew Lock: 310 ft^3 Observer Lock: 1,570 ft^3	1 x 10^{-2} to 760 torr	N/A
Dual Glove Box	42 In. H x 57 In. W x 16 In. L	1 x 10^{-5} to 760 torr	–300 to 300 °F
Chamber B	25 Ft Dia x 26 Ft H	1 x 10^{-6} to 760 torr	–300 °F – *

* Maximum temperature is dependent on characteristics of the test article and associated test buildup

Integrated Environment Testing

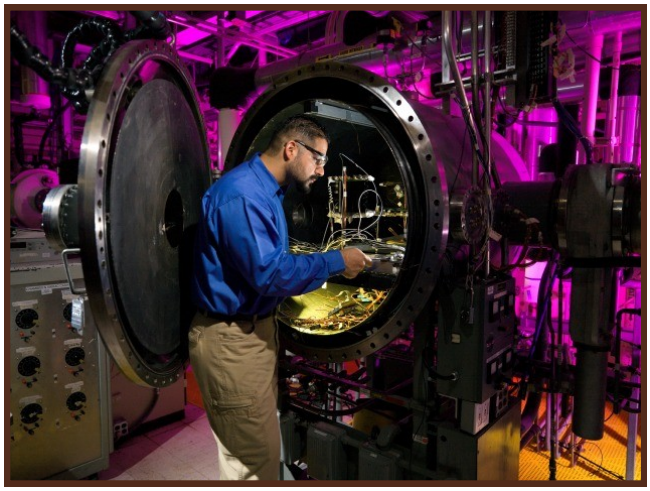
JSC environmental test facilities provide for simulation of launch, space, and entry environments. Additionally, we have the capability to evaluate electromagnetic compatibility and human performance in space and reduced-gravity environments. Tests of components, major spacecraft subassemblies, and complete spacecraft or payloads have the added advantage of including additional environments induced by the hardware itself, resulting in the highest possible simulation fidelity for the ground test and providing the greatest potential for evaluating spacecraft performance and discovering latent defects before committing hardware to flight.

Launch Environment



Electromagnetic Interference/Compatibility

Reentry Environment



Space Environment

Launch Environment

Rocket boosters and spacecraft are subjected to intense acoustic environments during launch, which induce high levels of vibration in structural elements and equipment. In addition, elastic structural interactions with propulsion systems and flight control systems can produce low-frequency, high-deflection flight instabilities. Ground testing to simulate launch-induced vibration or to investigate structural dynamics has proven to be vital in developing successful spacecraft programs.

Vibration Testing

Vibration testing is primarily performed in the General Vibration Laboratory (GVL), Spacecraft Vibration Laboratory (SVL), or Hazardous Vibration Test Stand. The GVL and SVL have very versatile test capabilities. Environmental testing includes simulation of broadband random vibrations induced in spacecraft by external acoustic or aerodynamic pressures, shock pulses to simulate ground handling or transportation conditions, broadband random environments for precipitating impending failures due to workmanship defects, and sine sweeps to identify resonances.

Services Provided

- Simulation of broadband random vibrations induced in spacecraft by external acoustic or aerodynamic pressures
- Shock pulses to simulate ground handling or transportation conditions
- Broadband random environments that do not simulate mission conditions but are appropriate for precipitating impending failures due to workmanship defects
- Sine sweeps to identify resonances
- Vibration of hazardous test articles, including pressurized systems and explosive materials
- Vibration in a thermal environment
- High-speed video and photogrammetry

Vibration Test Facility Specifications

Facility	Frequency Range	Shaker Size Range	Load Direction	Displacement
GVL	5 – 3,000 Hz	4,000 – 40,000 lb_f	x, y, or z	1 in. to 2 in. peak-to-peak
SVL	5 – 2,000 Hz	50 lb_f shakers up to 8 x 10,000 lb_f shakers	x, y, or z	2 in. peak to peak
Hazardous Vibration Test Stand	20 – 2,000 Hz	11,000 lb_f RMS Up to 16,000 lb_f sine Up to 15,500 lb_f random	x, y, or z	1 in. stroke

Integrated Environment Testing

General Vibration Laboratory

The GVL has five primary testbeds; however, unique testbeds can be constructed as necessary for a specific test project.
Inside the GVL enclosure (removable ceiling panels), the 40,000 lb_f shakers for the vertical and horizontal testbeds are mounted to seismic floors. Outside the GVL enclosure are two more testbeds—an 18,000 lb_f vertical testbed and a 20,000 lb_f horizontal testbed. Combined, these single-axis testbeds cover all three typically tested orthogonal axes . The GVL also houses an 8,000 lb_f human-rated vibration test-bed. The GVL typically provides testing for subsystems and smaller components, which range in size from items as large as an aircraft rudder to as small as a 4-oz heart rate monitor.

Human Rated Vibration Test Stand

Spacecraft Vibration Laboratory

The SVL was specifically designed for vibration testing of large structures and was used for Apollo, Skylab, space shuttle, and ISS tests. It provides a vast array of access platforms to the test articles. The SVL provides the test capability for high-force, low-frequency (5 to 50 Hz, generally) excitation of large structural assemblies. Massive test articles can be supported by pneumatic springs and subjected to high-force inputs, which simulate rocket-induced discrete-frequency or random loads with distributed mechanical shakers. The following are typical types of testing functions performed:

- High-force vibration (random)
- High-force vibration (sine)
- Shock vibration
- Fixed-base and free-free modal

Hazardous Vibration Test Stand

The Hazardous Vibration Test Stand provides for vibration of pressurized systems and explosive materials and vibration within a thermal environment. The test stand supports test articles (including the fixture) of up to 2,000 lb. Vibration capabilities include sine, random, and classical shock.

Hazardous Vibration Test Stand

Integrated Environment Testing

Acoustic Testing

JSC can perform a wide range of tests needed to evaluate exposure to harsh acoustic environments and audio communication system performance associated with the powered flight of aerospace vehicles. Capabilities include reverberant and progressive wave acoustic testing, electroacoustic and audio processing equipment testing, and audio and acoustic research. Vibroacoustic and sound transmission loss testing is primarily performed in the Spacecraft Acoustic Laboratory (SAL) or the Sonic Fatigue Laboratory (SFL). These two laboratories are very versatile in their test capabilities. The noise is generated by sending compressed air to the high- and low-frequency modulators, which in turn are coupled to the acoustic horns to generate the acoustic excitation in the reverberant chambers and progressive wave tubes. Audio and acoustic research is performed in the ADL.

Services Provided

- Simulations of broadband random vibrations induced in spacecraft by external acoustic pressures
- Vibroacoustic structural testing to high sound pressure levels of large structures, components, and small subsystems
- Closed-loop 1/3 octave band control system to provide decibel ranges in excess of 162 dB and the best possible spectrum shaping
- Sine sweeps to identify resonances
- Hemi-anechoic chambers for sound transmission loss testing
- Uniform simulated acoustic environments for performance testing electroacoustic devices
- Ultra-low ambient acoustic noise environment for testing microphone performance and characterizing acoustic emission sources
- Low acoustic noise environment used for audio recording and subjective audio performance testing

Acoustic Test Facility Specifications

Facility	Facility Size	Sound Pressure Level	Noise Generation
SAL	Reverberant chamber size: ~39 ft x 47 ft x 75 ft high Ceiling can be lowered to ~ 33 ft high	High Ceiling: 152 dB (current) 162 dB (future) Low Ceiling: 155 dB (current) 165 dB (future)	• Horn cutoff frequency selection (20 to 400 Hz) • 20 low-frequency air modulators (0 to 500 Hz) • 18 high-frequency air modulators (20 to 5,000 Hz) • Speakers (10,000 Hz) • Duration of run time at maximum overall sound pressure level is unlimited • Automated Holographic Array (36 microphones)
SFL	Reverberant chamber size: ~19 ft x 40 ft x 16 ft	158 dB (current) 167 dB (future)	
ADL	15 ft x 8 ft	125 dB SPL 30 to 500 Hz 115 dB SPL 500 to 8 kHz	

Integrated Environment Testing

Spacecraft Acoustic Laboratory

The SAL is world class. It has the second largest reverberant chamber in the world and provides the highest sound intensity and best low-frequency performance available in a large chamber, which makes it the largest chamber with the potential to produce over 160 dB. The SAL is equipped with a modular and movable ceiling and is designed to accommodate two different ceiling heights (75 ft and 32 ft 7.25 in., respectively).

Space Station P3/P4 Truss in SAL

Sonic Fatigue Laboratory

The SFL houses an exceptionally versatile medium-sized reverberant chamber. It is world class in having a reverberant chamber with the potential to produce one of the highest sound intensities in the world, producing +165 dB coupled with a hemi-anechoic chamber for sound transmission loss testing.

Audio Development Laboratory

The ADL provides for the design, development, test, and evaluation of audio sound equipment. The laboratory houses a reverberation chamber, a quiet room, and an anechoic chamber. For more information about our structural test capabilities, see Spacecraft Communications (page 7).

Integrated Environment Testing

Modal Testing

Modal testing consists of experimentally determining the resonance frequencies, corresponding mode shapes, and damping values for a structure. The Modal Operations Laboratory houses equipment and space for the setup, acquisition, and analysis of modal data. The test is usually set up in one of the other vibration or acoustic laboratories. Moveable, isolated seismic masses can be arranged to support massive test articles via air or coil springs, provide great flexibility in shaker locations, and allow easy access to the entire setup. Signal conditioning and data acquisition are accomplished by exciting a test structure with an electrodynamic shaker or a modally tuned impact hammer while measuring the input force and the output structural response.

Services Provided

- Modal characteristics
  - Natural frequencies
  - Damping ratios
  - Mode shapes
- Mathematical or finite element analysis model correlation
- Operating deflection shape analysis
- Fault detection

Capabilities
• Input excitation – flexible – Sine, random, burst random/chirp, sine on random (shaker driven) – Impact (impact hammer driven) – Operational (vibrating) test article • Shakers – wide array – Up to 500 lb capacity with single or multiple shakers – Impulse hammers available • Boundary condition capability – fixed-base, free-free – Large seismic mass bases up to 20,000 lb – Various isolation systems available – Multiple fixtures available

Structural Testing

JSC has expertise and facilities for tests ranging from mechanical properties testing of materials to full-scale verification testing of payloads and spacecraft structures. For more information about our structural test capabilities, see Structures and Materials (page 12).

Space Environment

JSC provides a wide array of space environment simulation test capabilities. Environments simulated include thermal, thermal-vacuum, vacuum, partial gravity, and space analogs. We have collected unique knowledge about what works well and what does not within the harsh environment of space. Test capabilities are available for both human-rated and hardware test environments.

Thermal Environment

JSC thermal test facilities offer a wide range of performance capabilities, which can be matched to the individual test requirements of smaller test articles or large test article components and subsystems.

Services Provided

- Temperature and humidity cycling
- Accurate determination of design factors, such as the following:
  - Operating temperatures
  - Changes in the absorptive or emissive properties of thermal coating
  - Changes in the electrical or mechanical properties of materials
- Accelerated electrical/electronic component burn-ins and life-cycle testing
- Environmental cycling (thermal/humidity) for materials survivability
- Battery performance and abuse testing

Thermal Test Facility Specifications

Facility	Size	Temperature Range
Thermotron	24 in. H x 24 in. W x 24 in. L	–90 to 350 °F
Chamber H	8 ft H x 8 ft W x 15 ft L	–150 to 200 °F
Chamber K	3 ft H x 3 ft W x 3 ft L	–250 to 350 °F
Chamber L	3 ft H x 3 ft W x 3 ft L	20 to 200 °F
Chamber T	27 in. H x 27 in. W x 29¾ in. L	–250 to 350 °F
8-Cubic-Foot Chamber	24 in. x 24 in. x 24 in.	–100 to 300 °F
32-Cubic-Foot Chamber	38 in. x 38 in. x 38 in.	–100 to 300 °F
Sun Thermal Chamber – 1	22 in. H x 22 in. W x 22 in. L	–300 to 400 °F
Sun Thermal Chamber – 2	22 in. H x 22 in. W x 22 in. L	–300 to 600 °F
3-Foot Thermal Box	3 ft H x 3 ft W x 3 ft L	–100 to 375 °F

Chamber T

Chamber T is a programmable-temperature enclosure. It can be programmed to automatically control the temperature and the rate of change between temperature extremes. The chamber is equipped with an observation window, two 4 in. x 4 in. glove ports, and a variable nitrogen purge for drying out the chamber environment and preventing moisture.

Chamber L

Chamber L can be used to control the temperature and humidity (range of 30 to 98 percent). Microprocessor-controlled profiles can be input to provide a wide range of temperature and humidity conditions. Although primarily designed for humidity control (which includes dewpoint and dry bulb temperature), the chamber can also be configured strictly for temperature tests.

Chamber L

Sun Thermal Chambers

The Sun Thermal Chambers are two chambers with programmable temperature enclosures. Both are equipped with 3-in. access ports, a glove box door, and a window.

Chamber T

Chamber K

Chamber K is a temperature enclosure that is programmable by means of a computerized controller. It can be programmed for any temperature profile desired, with variable soak times and rates of temperature change. The chamber is equipped with an observation window and two glove ports. It is remotely controlled with fully programmable temperatures and a variable nitrogen purge for drying out the chamber environment and preventing moisture.

Chamber H

Chamber H is a programmable-temperature enclosure for large test articles. It is automatically controlled to a user-defined temperature profile. The chamber is equipped with two observation windows, two glove ports below each window, and two 4 in. x 4 in. feed-through ports.

32-Cubic-Foot Chamber

The chamber is equipped with a 38-in. access door and 3-in. access ports.

Thermal-Vacuum Environment

JSC's thermal-vacuum test facilities provide thermal vacuum chamber test operations for both human-rated and hardware test environments. The facilities offer a wide range of performance capabilities, which can be matched to the individual test requirements of smaller test articles or large test article components and subsystems.

Services Provided

- Human-rated space environment testing
- Materials outgassing evaluations
- Accelerated electrical/electronic component burn-ins and life-cycle testing
- Environmental cycling for materials survivability
- Materials and hardware testing in extreme environments (manned/unmanned)
- Determination of design factors
  - Operating temperatures
  - Combined thermal and pressure-load distortions of dimensionally-critical structural elements
  - Fluid/gas leak rates
  - Changes in absorptive or emissive properties of thermal coating
  - Evolution of harmful or undesirable off-gassing products
  - Presence of conditions conducive to electrical-arc or corona discharge
- Integrated systems testing from engineering development to flight hardware for propulsion systems, cryogenic fluid management, battery power systems, fuel cells, pyrotechnics, space vehicle actuator systems, in-situ resource utilization, and auxiliary power units

Thermal-Vacuum Test Facility Specifications

Facility	Internal Volume	Temperature Range	Pressure Range
Chamber A	55 Ft Dia x 90 Ft H	–300 °F – *	1 x 10^{-6} to 760 torr
Chamber B	25 Ft Dia x 26 Ft H	–300 °F – *	1 x 10^{-6} to 760 torr
Dual Glove Box	4.5 Ft W x 3.5 Ft H x 1.3 Ft D	–300 °F to 300 °F	1 x 10^{-5} to 760 torr
Chamber E	4.6 Ft Dia x 9.5 Ft L	–280 °F – *	1 x 10^{-6} to 760 torr
Chamber N	3 Ft Dia x 3 Ft L	–280 °F – *	1 x 10^{-6} to 760 torr
Chamber P	5 Ft Dia x 4 Ft L	Ambient to 400 °F	1 x 10^{-6} to 760 torr
Chamber G	1.4 Ft Dia x 2 Ft L	–280 °F – *	1 x 10^{-6} to 760 torr
15-Foot Chamber	12.5 Ft diameter	–300 °F to 300 °F	1 x 10^{-6} to 760 torr
Tenney Chamber	43 In. W x 60 In. H x 26 In. D	–300 °F to 350 °F	5 x 10^{-5} to 760 torr
O_2 Effects Chamber	2 Ft Dia x 36 In. LH	–250 °F to 350 °F	0.0001 torr to 100 psia
Subsystem Chamber	17 Ft Dia	-200F to Ambient	1 x 10^{-2} to 760 torr

* Maximum temperature is dependent on characteristics of the test article and associated test buildup

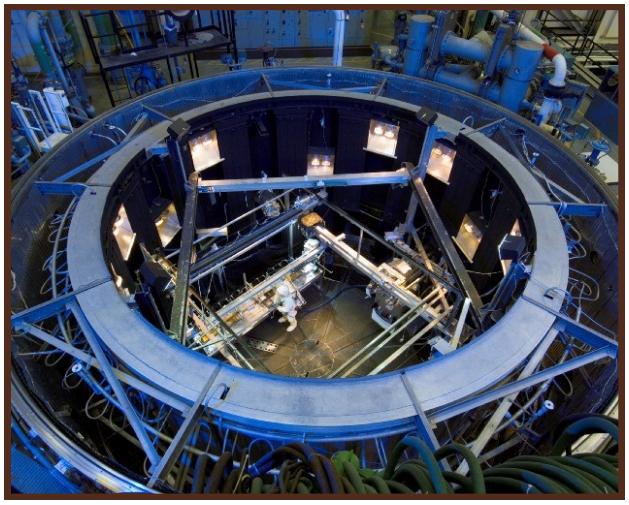
Integrated Environment Testing

Chamber A

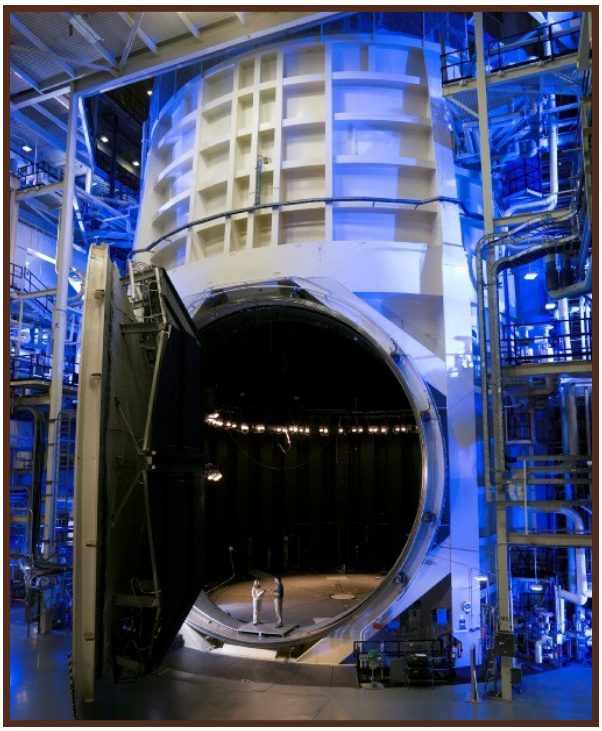
Chamber A is the largest of the thermal-vacuum test facilities at JSC. The chamber's usable test volume and high-fidelity space simulation capabilities are adaptable for thermal-vacuum testing of a wide variety of test articles, including entire space vehicles. Additional test support equipment includes mass spectrometers, infrared cameras, and television cameras. The numerous flanges at all levels provide ample pass-throughs for electrical wiring, instrumentation, and gases to support large systems.

Chamber B

Chamber B is used for human testing in a vacuum environment and for crewed space operations testing. Chamber B is a human-rated chamber equipped with a traversing monorail that provides weight relief to one suited crewmember at a time. The chamber also has dual crew locks to provide easy access to the test articles and a means of transporting test crewmembers to and from the test environment during tests.



Chamber B



Chamber A

Chamber E

Chamber E is a thermal vacuum chamber designed for relatively large gas loads at high vacuum. It is equipped with cold walls, an on-axis filtered xenon solar simulator, and pumping systems suitable for trace-contaminant-sensitive tests.

15-Foot Chamber

The 15-Foot Chamber is a spherical chamber designed to test advanced concepts for propulsion, propulsion feed systems, cryogenic fluid management, battery power systems, space vehicle actuators, and auxiliary power units.

Chamber P

Chamber P is a medium-sized chamber with vacuum capabilities and a heated shroud, making it a suitable candidate for hardware bakeouts.

Integrated Environment Testing

Vacuum Environment

JSC altitude chambers are used primarily for development, certification, and parametric testing of life support systems for man in the hostile environments of space. Each of the altitude chambers is configured for a particular type of testing; however, within the chamber's capabilities, each chamber complex may be used to perform other types of tests.

Services Provided

- Human-rated testing in a vacuum environment
- Space suit development testing
- Flight crew training
- Environmental control and life support system testing
  - Metabolic loading to life support systems
  - Parametric testing
  - Emergency and mobility accommodations of suited crewmember
- Air Revitalization System testing
  - CO_2 removal/reduction
  - O_2 generation
  - Trace contaminant control
- Materials and hardware testing in a vacuum environment

Altitude Test Facility Specifications

Facility	Internal Volume	Pressure Range
8-Foot Chamber	8 Ft Dia x 14 Ft L	1 x 10^{-2} to 760 torr
11-Foot Chamber	11 Ft Dia x 19 Ft L	1 x 10^{-2} to 760 torr
SSATA	Equipment Lock: 1,100 ft^3 Crew Lock: 310 ft^3 Observer Lock: 1,570 ft^3	1 x 10^{-2} to 760 torr
20-Foot Chamber	20 Ft Dia x 27.5 Ft H	1 x 10^{-2} to 760 torr
Chamber I	18 In. Dia x 29 In. L	1 x 10^{-2} to 760 torr

For more information about our altitude test capabilities, see EVA Systems Testing (page 33).

Integrated Environment Testing

Space Analog Environment

Analogs are designed to solve the unique challenges of living and working in extreme environments. JSC provides advanced concepts to NASA and the external community, using human factors as a design tool to develop products, systems, and architecture.

Services Provided

- Design and development of low-to-medium fidelity full-scale mockups of space vehicles and habitats
- Surface operation studies
- Space suit and vehicle requirements development
- Space suit and vehicle design evaluation
- Training with both space suited and shirt-sleeved participants
- Offloading of rover and robot weight
- Rendezvous and contact testing that requires low-friction movement of test articles along a flat surface

Planetary Analog Test Site

The Planetary Analog Test Site (a.k.a. the Rock Yard) provides a large multi-acre test area that simulates general features of the lunar and Martian surface terrain environment consisting of various slopes, grades, simulated craters, and strewn-rock field conditions.

Planetary Analog Test Site

Desert Research and Technology Studies (RATS)

Desert RATS is a NASA-led team of research partners working together to prepare for human-robotic exploration. The Desert RATS field test activity is the culmination of the year-long technology and operations development efforts of various individual science and advanced engineering discipline into a coordinated field test demonstration under representative (analog) planetary surface terrain conditions. The purpose of the RATS effort is to drive out preliminary exploration operational concepts for surface system requirements by providing hands-on experience with simulated planetary surface exploration hardware and procedures.

Integrated Environment Testing

Reduced Gravity

JSC provides the capability to simulate such reduced-gravity environments as lunar, Martian, or microgravity for testing, development, and training for human and hardware applications. Two facilities are primarily used for reduced-gravity simulation—the Active Response Gravity Offload System (ARGOS) and the Air Bearing Floor (ABF).

ARGOS

ARGOS is designed to simulate reduced-gravity environments, such as lunar, Martian, or microgravity, using a motion-control system. ARGOS supplies continuous offload of a portion of a subject's weight during dynamic motions, such as walking, running, and jumping, to simulate reduced gravity. The ARGOS facility follows the subject's motion in horizontal directions to maintain a vertical offload force. The steel structure was built to accommodate movement in all three directions of motion (one vertical and two horizontal). Dimensions are 41 ft x 24 ft x 18.5 ft.

Partial Gravity Space Suit Mobility Test

Air Bearing Floor

The ABF, or "flat floor", is a 70 ft x 98 ft epoxy surface designed to support rendezvous and contact testing that requires low-friction movement of test articles along a flat surface. Test articles are mounted on perforated pads that distribute a cushion of compressed air between the pads and the floor. The test articles "ride" on the air cushion and do not contact the floor. The floor is level within .003 in. per foot and .005 in. per 10 feet. It is polished to within 250 microinches' average deviation.

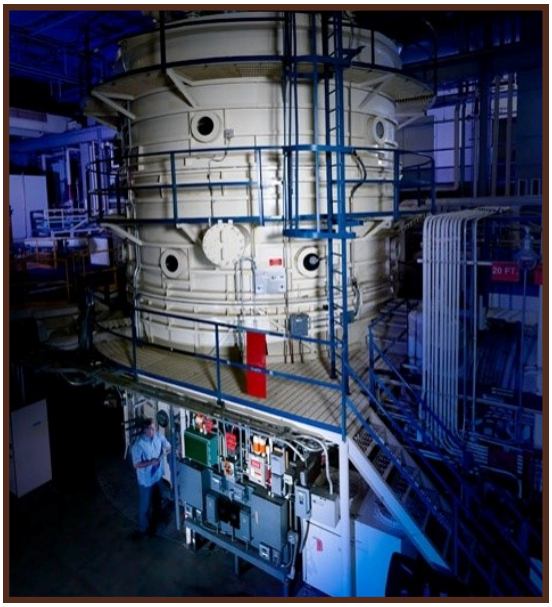
Integrated Environment Testing

Habitats

Habitats are designed to solve the unique challenges of living and working in extreme environments. JSC provides advanced concepts to NASA and the external community using Human Factors as a design tool to develop products, systems, and architecture. Our team ensures successful human habitation and performance in space through the development of early and iterative conceptual designs, models and mockups of habitation systems, hardware, and architectural concepts. Evaluations investigate crew interface designs and operating concepts to predict human and machine performance in space and to generate design requirements.

20-Foot Chamber

The 20-Foot Chamber is a vacuum chamber with an airlock and a rapid decompression chamber. The volume is divided into three levels by non-pressure-bearing floors, which provide atmospheric isolation. Chamber configurations can support both long-duration human habitability and unmanned testing of life support equipment and systems.



20-Foot Chamber

20-Foot Chamber Specifications

Internal Volume	Pressure Range
20 Ft Dia x 27.5 Ft H	1×10^{-2} to 760 torr

Mockup Development Facility

Provides for the development of low-to-medium-fidelity full-scale mockups of space vehicles and habitats. Mockups developed include a horizontal axis cylindrical habitat module, a toroidal habitat module, a Lander translation tunnel test article, a descent stage mockup, and a vertical-axis cylindrical habitat demonstration test article. Testing of these mockups can be performed in place at JSC or can, in some cases, be performed at analog field test sites or in reduced-gravity aircraft.

Mockup Development Facility

Reentry Environment

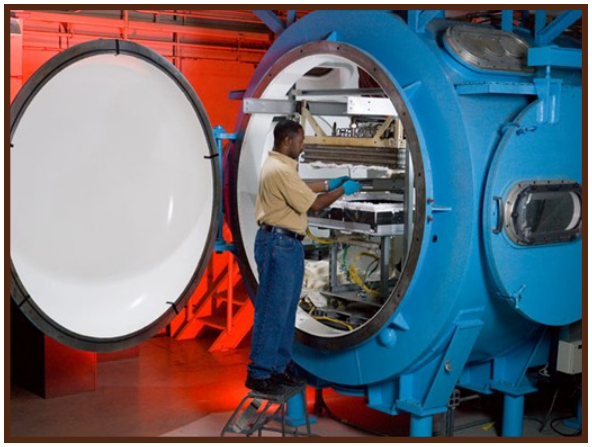
JSC has expertise and facilities for the simulation and testing of the aerothermal heating experienced by spacecraft as they enter planetary atmospheres. The 13 Megawatt Arc Tunnel provides the capability to perform aerothermal heating environment tests necessary for the screening, development, and certification of spacecraft TPSs. This facility is a high-altitude, hypersonic wind tunnel facility that uses electric power to heat and accelerate air to simulate convective heating conditions experienced by spacecraft during reentry.
The Radiant Heating Test Facility provides the capability to perform multizone, high-temperature radiant heat testing of large spacecraft TPSs and associated structures in a controlled pressure environment to simulate reentry thermal profiles, thermal gradient, and pressure.

Services Provided

- Earth (air test gas), Mars, and Venus planetary entry testing (CO_2 test gas)
- Basic material testing and screening
- Development testing – gaps, seals, and attachments
- "Clipped" hardware – Reaction Control System nozzles, antennas, instrument penetration, windows, and hatches
- Sustaining engineering
  - Orbital debris
  - Design changes
  - Recertification of materials
- Simulation of the following:
  - Ascent heating and pressure decay
  - On-orbit cold soak
  - Reentry heating and pressure
- Large-scale system tests
  - Nose cap
  - Wing leading edge
- Small-scale tests
  - Materials screening
  - Conductivity testing
  - Advanced materials

Radiant Heating Test Facility

Parameter	Radiant Heat 1	Radiant Heat 2
Chamber dimensions	10 ft x 18 ft	92 in. x 92 in.
Article size	72 in. x 110 in.	24 in. x 24 in.
Gas	Air, N_2	
Pressure range	0.1 to 760 torr	
Temperature range	300 °F to 3,200 °F	
Radiative heating rate	0 to 90 BTU/ft^2 – Sec entry pro-file, 22 zones	0 to 90 BTU/ft^2 – entry profile, 1 zone
Test article type	Flat, radically curved	Flat, small curvature
Heater	1 to 5 MW	

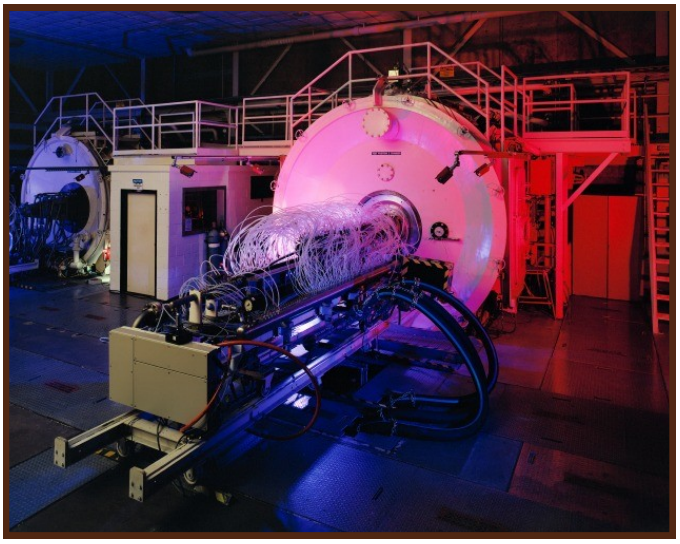


Radiant Heating Test Facility – Radiant Heat 1

Atmospheric Reentry Materials and Structures Evaluation Facility (ARMSEF)

Unique Capabilities

- Variable O_2 test gas concentration for material characterization
- Variety of wedges/holders: 4.5 x 5.0 to 24 x 24 in. or custom built to customer needs
- Heater configuration is highly flexible for adjustment of test envelope capability
- Rapid scanning spectroradiometer
  - 0.68 to 8.0 µm wavelength range
  - 432 spectral intensity measurements at discrete wavelengths
- Range of nozzles: 3.5- to 40-in. diameter
- 4 DC rectifiers capable of continuously producing a 10 MW or 13 MW peak



Atmospheric Reentry Materials and Structures Evaluation Facility

Parameter	Conical Nozzle		Channel Nozzle
Gas	N_2 + O_2 (0 to 50% O_2), CO_2		N_2 + O_2 (0 to 50% O_2), CO_2
Input power	0.5 to 13 MW		0.5 to 13 MW
Nozzle exit (inches)	3.5, 5, 7.5, 10, 12, 15, 18, 20, 25, 30, 35, and 40		2 x 10, 2 x 18, 2 x 30 Height x width at test article center
Bulk enthalpy (BTU/lbm)	1,500 to 20,000		1,500 to 20,000
Type of test article	Stagnation	Wedge	Flat panel
Sample size (inches)	27 Dia. maximum	3 x 3, 4.5 x 5, 6 x 6, 12 x 12, 24.5 x 24.5	4 x 4, 12 x 12, 24 x 24, 8 x 10
Convective heating rate (BTU/ft^2 – Sec)	0.5 to 1,300	0.5 to 234	12 in. x 12 in.: 2 to 78 24 in. x 24 in.: 2 to 45
Surface pressure (psf)	2 to 1,000		4 to 110
Surface temperature	400 to 5,500 °F*		1,000 to 3,100 °F*

* Maximum temperature is dependent on material

Electromagnetic Interference/Compatibility Environment

The Electromagnetic Interference/Electromagnetic Compatibility (EMI/EMC) Control Test and Measurement Facility supports engineering development and provides EMI/EMC evaluation and certification testing of crew, flight, and ground support equipment including, but not limited to, communication, instrumentation, biomedical, guidance and navigation, computation, and robotics.

Services Provided

- Developmental, engineering support, performance and precertification evaluation, and certification testing
- Conducted and radiated emissions and susceptibility testing (e.g., MIL-STD-461, all revisions; DO-160, sections 16 through 21)
- Lightning indirect effects and Electrostatic Discharge (ESD) assessment (e.g., DO-160, sections 22 and 25)
- Cable transfer impedance and equipment shielding effectiveness assessment
- EMC design consultation
- Detailed test planning support and test data collection/reporting

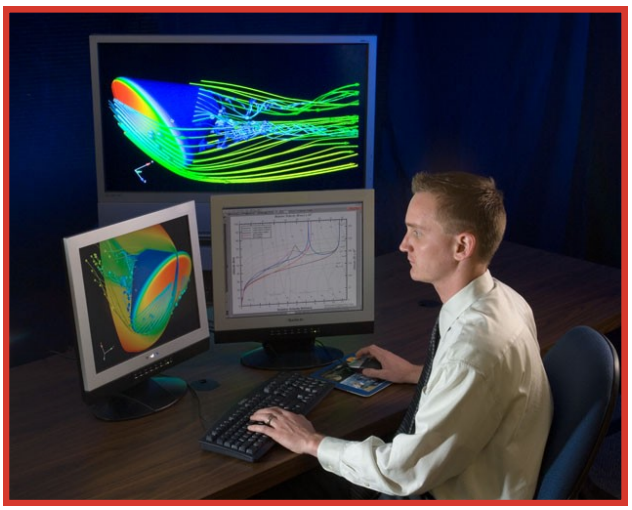
EMI/EMC Laboratory

Capabilities	
Shielded room enclosures	Meet military standard MIL-STD-285
Synthesized signal generators	Capable of covering a frequency range of 10 Hz to 26 GHz
RF power amplifiers	Provide up to 500 W of output power in the frequency range of 10 kHz to 18 GHz
Lightning transient generator and support probes	Provide test waveforms 1, 3A, 3B, 4, and 5A for lightning indirect effects testing up to Level 3
Electrostatic discharge test equipment	Provides standard ESD test waveforms up to a 30 kV peak pulse voltage
Complete line of general purpose ancillary test equipment	Power supplies, oscilloscopes, power meters, and voltmeters
High-fidelity EMC modeling software	General purpose 3-D electromagnetic modeling

Flight Design

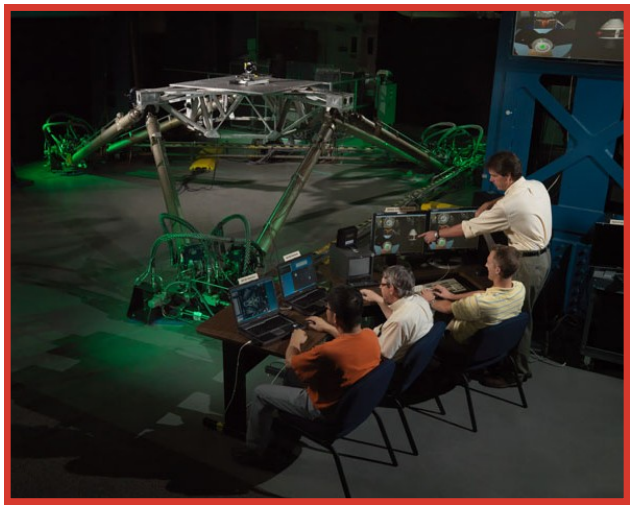
Aerodynamics, aerothermodynamics, fluid dynamics, GN&C, flight performance, and mission design are only a few JSC engineering strengths. JSC also provides engineering, design, development, testing, and evaluation for all phases of spaceflight (launch, ascent, orbit, and entry) for all spacecraft.

Guidance, Navigation, and Control



Aerodynamics

Entry, Descent, and Landing



Proximity, Rendezvous, and Docking

Guidance, Navigation, and Control

JSC provides technical leadership in the disciplines of guidance, navigation, and control (GN&C), and autonomous and intelligent GN&C systems. JSC personnel perform system requirements definition, analysis, design, and testing necessary to support the development of GN&C system designs and to verify the compatibility of the designs with functional and performance requirements. JSC also provides the technical expertise and facilities to support GN&C hardware and software development, testing, and verification. This includes real-time hardware-in-the-loop and pilot-in-the-loop simulations; end-to-end GN&C system test and verification; and navigation systems definition, design, development, and test.

Services Provided

- GN&C flight hardware and software development, test, and verification – hardware and software interaction testing
- Spacecraft GN&C simulation design and development – real-time hardware-in-the-loop and pilot-in-the-loop testing
- GN&C analysis – system requirements, functional architectures, system algorithms, system software requirements, dynamics, and control interaction
- Navigation architecture and algorithm design, analysis, and development and integration with navigation hardware design and testing
- Automated Rendezvous, Proximity Operations, Docking, and Undocking (RPODU) design, analysis, and operations – guidance and targeting algorithm design and analysis for RPODU

- Low Earth Orbit (LEO), Geosynchronous Earth Orbit (GEO), cis-lunar orbit, and interplanetary missions: trajectory optimization, design, and performance analyses
- Flight phase development and performance characteristics for ascent, orbit, interplanetary, deorbit, entry, skip-entry, aerocapture, and landing mission phases

Global Positioning System Laboratory (GPSL)

The GPSL is a design, development, testing, and evaluation facility that allows testing of Global Positioning System (GPS) equipment with live GPS satellite signals via rooftop antennas and antenna positioners.

Advanced GN&C Development Laboratory

Advanced GN&C Development Laboratory

The AGDL serves as a center of excellence for the development and evaluation of advanced GN&C systems. The laboratory provides the computational resources required to build high-fidelity six-degree-of-freedom simulations of single- and multiple-vehicle missions for various flight phases. It also provides excellent visualization capabilities and real-time (human-in-the-loop) simulation capabilities. The AGDL features Linux-powered blade servers with more than 300 cores used to run Monte Carlo analyses, scheduling the blade resources through the open source scheduling software. This software allows engineers to submit their 2,000- or 3,000-run Monte Carlo analysis simulations to the laboratory and have those jobs automatically distributed across all the blades along with the jobs of the other engineers in the laboratory. The AGDL makes extensive use of the Trick simulation environment and maintains a comprehensive suite of Trick-compliant simulation models for modeling rendezvous, proximity operations, and capture.

The AGDL also provides rapid hardware and software development, real-time hardware-in-the-loop simulation, and end-to-end GN&C system verification as well as development and evaluation of space-based navigation systems, including the design and development of space capable GPS receivers. Additional investigations include

- Absolute and relative on-orbit GPS navigation analysis
- Refined navigation filtering and sensor measurement combining
- Sensor analysis, particularly optical, RF, and inertial sensors

The AGDL also is home to specialized GPS and inertial test capability as referenced in the following tables:

GPS Signal Generator Specifications

Model	Output	Channels	Frequency	GPS Attitude Capable?	Notes
Spirent 7700	4 RF	12	L1 Only	Yes	Rack Mounted/Portable
Spirent 4760	4 RF	16	L1 Only	Yes	Rack Mounted/Portable
Spirent 6560	4 RF	12	L1 Only	Yes	Rack Mounted/Portable

3-Axis Rate Table Specifications

Table	Rotation Rates	Position Accuracy	Rotational Accuracy
Acutronic Model 357L	500 deg/sec – Outer Gimbal 1000 deg/sec – Middle Gimbal 1500 deg/sec – Inner Gimbal	5 arc sec (All Gimbals)	0.1% at 1 deg/s 0.01% at 10 deg/s 0.001% at 10 deg/s

Rendezvous, Proximity, and Docking

Orbital dynamics make rendezvous and proximity operations a complex task. JSC provides ground facilities, including real-time simulators for development, testing, and training for spacecraft proximity, rendezvous, and docking operations.

Systems Engineering Simulator

The SES is a real-time crew-in-the-loop engineering simulator for ISS and advanced programs. The facility simulates multiple free-flying vehicles with accurate six-degree-of-freedom equations of motion. For more information about the SES, see Models, Simulation, and Software (page 18).

Six-Degree-of-Freedom Dynamic Test System

The SDTS is a real-time, six degree-of-freedom, short-range simulator with a motion base designed to simulate the relative dynamics of two bodies in space mating together (i.e., docking or berthing). The SDTS has the capability to test full-scale docking and berthing systems.

- Repositionable, stationary upper platform
- Motion base is a hydraulic-powered Stewart platform, capable of supporting a 3,500-lb payload

Simulation is controlled by interconnected computers running real-time simulation software. The motion base can also be used for nonmating applications (e.g., docking sensors, instruments).

SDTS Specifications

Parameter	Value
Payload capacity	3,500 lbm
Lateral motion range (average)	±40 in.
Lateral motion range (peak)	±62 in.
Vertical motion range (maximum)	124 in.
Angular motion range	±20°
Data channels available (analog)	96
Motion table bandwidth (typical)	8 Hz
Inner control loop (DCS) (typical)	800 Hz
Outer control loop (SimHost) (typical)	200 Hz
Position error (typical)	0.03 in.
Incremental accuracy (typical)	0.006 in.
Absolute accuracy (typical)	±0.01 in.

Six-Degree-of-Freedom Dynamic Test System

Flight Mechanics

JSC provides design and evaluation of mission concepts, vehicle flight performance capabilities and requirements, and preliminary GN&C requirements. This includes flight envelopes and trajectories for ascent, targeting and profiles for on-orbit rendezvous, interplanetary trajectories, and entry through landing designs. These efforts also include assessments of system requirements, such as those related to GN&C architecture, propulsion, thermal protection, aerodynamics, and decelerators. Launch and landing capability windows are defined, as well as guidance algorithms developed to produce the desired trajectory performance. JSC provides end-to-end mission design and vehicle performance analysis for all current and advanced vehicle concepts for LEO, lunar, and planetary missions.

Flight Mechanics Laboratory

The laboratory uses a high-performance Linux computing cluster along with many specially designed software tools to solve various flight mechanical issues, including the following:

Design Reference Missions

- End-to-end mission design
- Mission phase trajectories development
  - Ascent/on-orbit/rendezvous
  - De-orbit/entry/descent/landing
  - Aerocapture
  - Interplanetary
- Constraint envelopes and corridors
  - Launch windows
  - Landing opportunities
  - Entry corridors
  - Footprints

Vehicle Performance

- Vehicle capabilities and requirements
- Flight performance definition
- GN&C requirements and algorithms
- Vehicle dynamics
- Parachute systems design/performance
- Entry demise/debris predictions
- Flight performance visualization

Entry, Descent, and Landing

Energy dissipation in a short amount of time, high entry velocities, composition of the atmosphere, and hitting the target encompass the challenges of planning for entry, descent, and landing. JSC provides a combination of ground test, analytical, and flight test capabilities needed to develop entry, descent, and landing systems.

Yuma Proving Ground

JSC has access to a remote facility at the United States Army Yuma Proving Ground for air delivery testing of parachute systems. The facility provides the capability to perform design limit load, integrated launch abort, and drop testing of parachute systems.

Yuma Proving Ground

Atmospheric Reentry Testing

JSC has expertise and facilities for the simulation and testing of the aerothermal heating experienced by spacecraft as they enter planetary atmospheres. The 13 Megawatt Arc Tunnel provides the capability to perform aerothermal heating environment tests necessary for the screening, development, and certification of spacecraft TPSs. For more information about our TPS test capabilities, see Reentry Environment (page 49).

Hardware-in-the-Loop ALHAT System Testbed

The laboratory integrates software models of vehicle dynamics and systems with hardware models (e.g., sensors) to provide real-time simulation of closed-loop lander systems supporting ALHAT. For more information about HAST, see Models, Simulation, and Software (page 18).

Flight Mechanics Laboratory

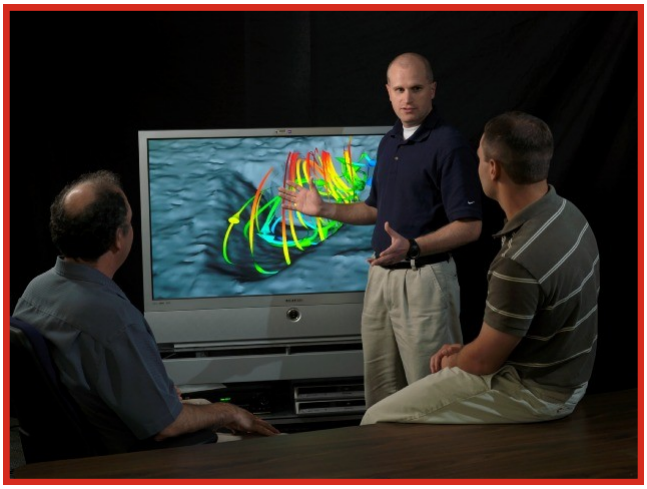
The laboratory uses a high-performance Linux computing cluster along with many specially designed software tools to solve various flight mechanical disciplines, including performance optimization, parachute deployment through landing dynamics, entry trajectory design, hazard avoidance, and autonomous landing. For more information about our Flight Mechanics Laboratory capabilities, see Flight Mechanics (page 56).

Aerodynamics

JSC offers technical leadership in the engineering disciplines of aerodynamics, aerothermodynamics, and fluid dynamics. JSC maintains a highly skilled and experienced workforce, premier laboratories and test facilities, and state-of-the-art analysis tools and databases.

Services Provided

- Computational resources to assist in studies of fluid dynamics, aerodynamics, and aerothermodynamics
  - Aerodynamic performance and loads
  - Aerothermal environments
  - On-orbit aerodynamics
  - Plume-induced environments
  - Parachute/flexible structure aerodynamics
  - Computational fluid dynamics
  - Rarified gas dynamics
- Ground and flight testing
- Model development
  - Computer-Aided Design (CAD) model generation
  - Computational fluid dynamics grid generation
  - Flowfield visualization



Aerodynamics Tools Available	
• CART 3-D – Inviscid computational fluid dynamics analysis package for conceptual and preliminary aerodynamic design • Chimera Grid Tools – Toolbox for scriptable grid generation • Computational Analysis Programming Interface – Tool for CAD interface • DAC – Direct simulation Monte Carlo analysis code for rarified gas dynamics • DEBRIS – Code for performing debris transport analysis • DPLR – Hypersonic computational fluid dynamics solver • FIELDVIEW – Tool for flow visualization of computational fluid dynamics solutions	• FREEMO – Free molecular aerodynamics engineering tool • FIN-S – Navier-Stokes solver based on finite element method • GRIDGEN – 3-D grid generator for complex geometries in a production environment • GRIDPRO – Grid generation software • OVERFLOW – Navier-Stokes computational fluid dynamics solver for structured grids • RPM3D– Engineering tool for plume impingement effects (particularly heating) • SNEWT – Newtonian aerodynamics engineering tool • TECPLOT – 2-D and 3-D plotting and flow visualization package

Robotics

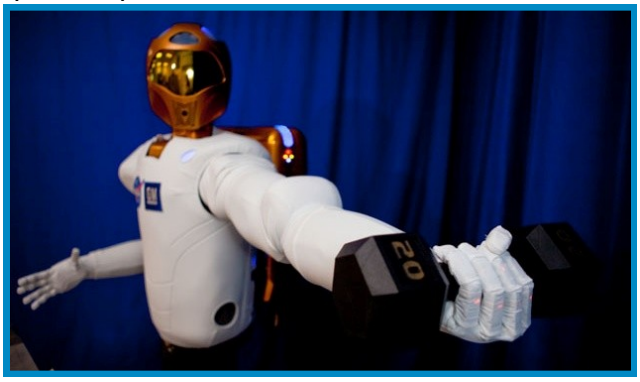
JSC provides research, engineering, development, integration, and testing of robotic hardware and software technologies for robotic systems applications in support of human spaceflight. Our technology development laboratories have produced the Robonaut, an anthropomorphic robot with a dexterity close to that of humans, and the Lunar Electric Rover, which was on display in the 2009 Presidential Inaugural Parade.

Services Provided

- Design and development of highly dexterous manipulators
  - Force-controlled manipulation
  - Variable stiffness joints
  - Human-like end effectors
  - Integrated machine vision
  - Human-compatible robot operations
- Design and development of electric vehicles for extra-planetary or terrestrial off-road use in extreme environments
  - Active suspension systems
  - Efficient transmissions
  - Vehicle autonomy and navigation
  - Efficient motor control
  - High-voltage DC systems
- Design and development of robotic interfaces
- Design and development of free-flying robotic micro/nanosatellite-class platforms
- Robotic interface and system requirements definition and verification
- Robotic capture and berthing analysis of free-flying vehicles
- Simulation and verification of robotic workstation interfaces
- Physical emulation of robotic devices with motion platforms

Robotic Technology Development Laboratories

JSC has expertise in design, development, and testing of robotic technology. The Center offers the capability to develop highly advanced robotics systems, such as Robonaut, and provides for the development of advanced perception, machine vision, and sensing capabilities. JSC personnel can assemble and test mobility system technologies, such as the Space Exploration Vehicle.



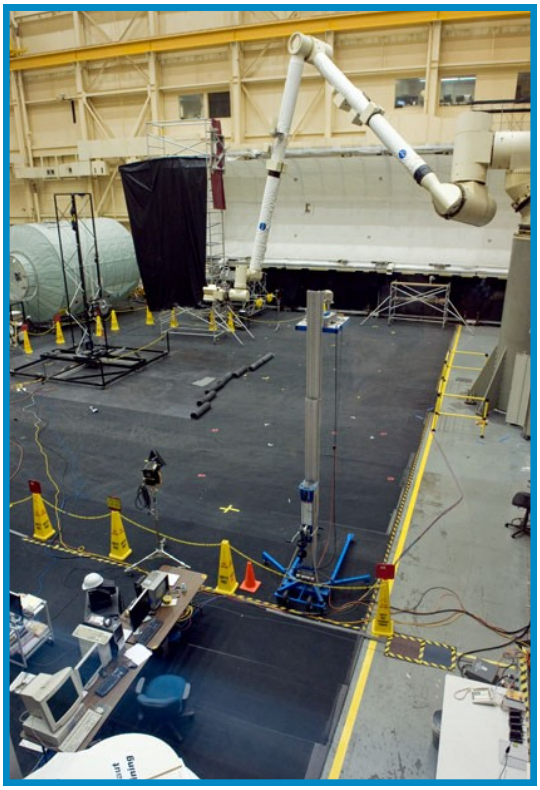
Robonaut 2

Space Exploration Vehicle

Robotic Motion Platform

The RMP is a very large model-following motion-base simulator that is hydraulically actuated, computer-controlled, and designed to maneuver payloads of up to 500 lb at the end of its 60-foot-long robotic arm. A model-following closed-loop control system allows the RMP to emulate any simulated system as long as the desired motions are within its rate and travel limits. Services include the following:

- Emulation of the Space Station Remote Manipulator System
- Three-degree-of-freedom free-flyer capture simulation
- Payload integration and development



Robotic Motion Platform

RMP Specifications

Parameter	Value
End effector translational velocity	14 in/s
End effector rotational velocity	10 d/s
Degrees of freedom	8
Number of joints	7
Joint velocity	0.08 to 5 d/s
Joint reach limits	± 270 degrees
Arm reach limits	100-ft Dia hemisphere
Payload capacity	500 lb
Absolute POR linear position accuracy	± 3.04 in.

Dexterous Manipulator Testbed

The DMT provides two 6-joint hydraulic manipulators with model-following control systems, mounted on a 7-foot-high pedestal, designed to precisely position small payloads of up to 240 lb for close-in worksite operations, concentrating on hardware contact.

DMT Specifications

Parameter	Value
Arm reach limit	72 in.
Arm lift capacity	240 lb
Degrees of freedom	6
Joint velocity	0.08 to 5 d/s

Acronyms

3-D	Three-Dimensional
ABF	Air Bearing Floor
ACES	Advanced Crew Escape Space Suit System
ADL	Audio Development Laboratory
AGDL	Advanced GN&C Development Laboratory
ALHAT	Autonomous Landing and Hazard Avoidance Technology
ARGOS	Active Response Gravity Offload System
ARMSEF	Atmospheric Reentry Materials and Structures Evaluation Facility
ARTEF	Air Revitalization Technology Evaluation Facility
ATCS	Active Thermal Control System
ATF	Antenna Test Facility
AUT	Antenna Under Test
AWRSDF	Advanced Water Recovery Systems Development Facility
BTU	British Thermal Unit
CAD	Computer-Aided Design
CEM	Computational Electromagnetics
CSSL	Communication Systems Simulation Laboratory
CT	Computed Tomography
DC	Direct Current
DIC	Differential Interference Contrast
DMT	Dexterous Manipulator Testbed
EDGE	Engineering DOUG Graphics for Exploration
EEST	Exploration Electrical Systems Testbed
EMI/EMC	Electromagnetic Interference/Electromagnetic Compatibility
EMU	Extravehicular Mobility Unit
ESD	Electrostatic Discharge
ESTL	Electronic Systems Test Laboratory
ET	Eddy Current Testing
EVA	Extravehicular Activity
FDIR	Fault Detection, Isolation, and Recovery
FIR	Flash Infrared
GEO	Geosynchronous Earth Orbit
GLACIER	General Laboratory Active Cryogenic ISS Equipment
GN&C	Guidance, Navigation, and Control
GPS	Global Positioning System
GPSL	Global Positioning System Laboratory
GVL	General Vibration Laboratory
HAST	Hardware-in-the-Loop ALHAT System Testbed
HD	High-Definition
ICEPAC	ISS Cold Enclosure PCM Augmenting Capsule
IGOAL	Integrated Graphics Operations and Analysis Laboratory
IR	Infrared
ISS	International Space Station
IVA	Intravehicular Activity
JSC	Johnson Space Center
LEO	Low Earth Orbit
Li-ion	Lithium Ion
LSS	Life Support Subsystem
MELFI	Minus Eighty degree Laboratory Freezer for ISS

Acronyms

MT	Magnetic Particle
NDE	Nondestructive Evaluation
NSI	NASA Standard Initiator
PCM	Phase Change Material
PT	Liquid Penetrant
RATS	Research and Technology Studies
RF	Radio Frequency
RFID	Radio Frequency Identification
RMP	Robotic Motion Platform
RMS	Root Mean Square
ROC	Reconfigurable Operational Cockpit
RPODU	Rendezvous, Proximity Operations, Docking, and Undocking
RT	Radiographic Testing
SAFER	Simplified Aid for EVA Rescue
SAL	Spacecraft Acoustic Laboratory
SDTS	Six-Degree-of-Freedom Dynamic Test System
SES	Systems Engineering Simulator
SFL	Sonic Fatigue Laboratory
SPL	Sound Pressure Level
SSATA	Space Station Airlock Test Article
STL	Structures Test Laboratory
SVL	Spacecraft Vibration Laboratory
TDRS	Tracking and Data Relay Satellite
TDRSS	Tracking and Data Relay Satellite System
TPS	Thermal Protection System
UT	Ultrasonic Testing
VRL	Virtual Reality Laboratory
VSM	Vehicle Systems Management
WRFID	Wireless and Radio Frequency Identification
WWCTS	Wastewater Collection and Transportation System

Facility Index

Facility Index

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NP-2011-07-042-JSC